ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

FLEXURAL PERFORMANCE EVALUATION OF DIFFERENT COUNTRIES CONCRETE SLEEPERS FOR THE CASE OF ETHIOPIAN RAILWAY TRACK DESIGN

A Thesis Submitted to the School of Graduation Studies of Addis Ababa University in the Partial Fulfillment of the Requirements for the Degree of Masters of Science in Railway Engineering

By

Mesfin Kebede

Advisors:

Tatek Fikadu (Phd) [1]

Mequanent Mulugeta (Msc.) [2]

July 2015

---

[1] Principal Engineer, Norwegian Public Roads Administration, Planning and Engineering Services Division

[2] Lecturer, Addis Ababa Institute of Technology, School of Civil and Environmental Engineering (Road and Railway Engineering Division)

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

FLEXURAL PERFORMANCE EVALUATION OF DIFFERENT COUNTRIES CONCRETE SLEEPERS FOR THE CASE OF ETHIOPIAN RAILWAY TRACK DESIGN

By

Mesfin Kebede

July 2015

Approved by Board of Examiners

Dr. Tatek Fikadu ____________________ ____________________
Advisor Signature Date

Ato Mequanent Mulugeta ____________________ ____________________
Co-Advisor Signature Date

Dr. Esayas G/Yuhannes ____________________ ____________________
External Examiner Signature Date

Ato Matias Kabtamu ____________________ ____________________
Internal Examiner Signature Date

Dr. Birhanu Beshah ____________________ ____________________
Chairman Signature Date

Acknowledgements

I would like to give my sincere thanks to my advisor Dr. Tatek Fekadu for his continuous advice, guidance and encouragement throughout this research project.

I would also like to thank Mr. Mequanent Mulugeta my co-advisor, for his advice and support specially in modeling areas.

Special thanks to my love Haymanot Nigussie for her advice and encouragement from starting to the end of my thesis.

Abstract

Prestressed concrete sleepers are the most widely used sleeper type in various countries for railway track system. This thesis evaluates the flexural performance of Australian German, British and Chinese prestressed concrete sleepers in comparison with the currently used sleeper in Ethiopia. The state of art of literature review has been discussed in order to assess the experiences of these countries in railway prestressed concrete sleeper. Codes of standards for prestressed sleeper recommended different types of concrete sleepers according to track gauge and axle load capacity. Sleepers are subjected to different types of load such as quasistatic, dynamic load and combined quasistatic and dynamic loading. In some codes like British and German accidental, exceptional and services load are included in the design.

Finite element (FE) modeling and analysis is performed using FE software packages ANSYS. The design rail seat load is calculated according to the code provisions of respective countries code of standard. For comparison of the results of rail seat and sleepers center positive and negative loadings, AREMA standard is used as a reference. The result obtained from both rail seat positive and negative loads shows a good result which is below AREMA recommendations. For results obtained from sleeper center loading there was a variation of about average of 20%. The second FE analysis has been conducted according to actual ballast pressure distribution under sleepers provided by each country code and Chinese code. From the analysis result it has been observed that, the Australian and German concrete sleeper shows a good response at rail seat and sleeper center respectively. The German concrete sleeper relatively shows a better result when compared to British concrete sleeper under both rail seat and sleeper center. Finally, dynamic analysis has been made to see how these loads affect the flexural performance of concrete sleepers. The result showed that the Australian and china concrete sleepers observed a large amount of deflection when compared to other. In contrast the German concrete sleeper showed a small deflection. Based on the analysis result the German concrete sleeper was selected in terms of its general flexural performance. Lastly, the recommended sleeper cross-section shows a reduced stress when compared with others concrete sleepers.

KEY WORDS: Prestressed concrete sleepers, Flexural performance; Rail seat bending moment; Sleeper center bending moment, Dynamic analysis

Table of Contents

Acknowledgements ii

Abstract iii

List of Figures viii

List of Tables ix

Appendix x

Notation xi

Acronyms xv

CHAPTER ONE 1

INTRODUCTION 1

- 1.1. Background 1
- 1.2. Statement of the problem 2
- 1.3. Research methodology 2
- 1.4. Scope of the Research 4
- 1.5. Research objectives 4

CHAPTER TWO 5

LITERATURE REVIEW 5

- 2.1. Development of sleeper 5
- 2.2. Ideal sleeper 5
- 2.3. Spacing of sleepers 5
- 2.4. Types of Sleeper 6
  - 2.4.1. Wooden Sleeper 6
  - 2.4.2. Steel Sleeper 6
  - 2.4.3. Concrete Sleeper 7
  - 2.4.3.1. Prestressed concrete mono-block sleepers 7
  - 2.4.3.2. Twin block sleepers 9
  - 2.4.3.3. Frame sleeper 10

2.4.3.4. Wide Sleepers 11
2.4.3.5. Twin Sleepers.. 15
2.5. Factors affecting the performance of concrete sleepers 16
2.5.1. Cracking and Failure at Rail Seat 16
2.5.2. Cracking and Failure at Mid-span 16
2.5.3. Concrete deterioration.. 17
CHAPTER THREE.. 18
ASSESSMENT OF STANDARDS FOR CONCRETE SLEEPERS 18
3. Australian railway concrete sleepers standard.. 18
3.1. Sleepers type and dimension according to ARTC 18
3.2. Material requirement... 19
3.3. Design of Sleepers 19
3.3.1. Design Forces (vertical wheel load) 20
3.3.2. Load distribution on the sleeper 20
3.3.3. Rail seat load 22
3.3.4. Ballast and ballast pressure 22
3.3.5. Design moment.. 22
3.4. British railway concrete sleepers standard 24
3.4.1. Material requirement of concrete sleepers 25
3.4.2. Loads.. 25
3.4.3. Method of bending moment determination.. 26
3.4.4. Cracks in concrete sleepers 26
3.4.5. Distribution of longitudinal load 26
3.4.6. Distribution of ballast reaction along the length of the sleeper....................... 28
3.4.7. Attenuation of impact loads by fastening system 29
3.4.8. Design of concrete sleeper according to BS EN 13230-6............................... 30
3.4.8.1. Calculation of normal dynamic rail seat load P_k.. 30

3.4.8.2. Calculation of the characteristics bending moment 30

3.5. German railway concrete sleepers 32

3.5.5. Material requirement.. 32

3.5.6. Dimensions 33

3.5.7. Load 34

3.5.8. Load distribution... 34

3.5.9. Bending moment calculations 34

3.5.9.1. Positive bending moment at the rail seat (M_{dr})... 35

3.5.9.2. Negative bending moment at the rail seat (M_{drn}) 36

3.5.9.3. Bending moment at the center 36

3.6. China railway concrete sleepers 36

3.6.5. Type and dimensions of concrete sleepers... 36

3.6.6. Design bending moment 37

3.6.6.1. Maximum positive moment under the rail.. 37

3.6.6.2. Maximum negative moment at the middle 38

3.6.7. The Chinese concrete sleepers production in Ethiopia 39

CHAPTER FOUR.. 40

MODELING OF RAILWAY PRESTRESSED CONCRETE SLEEPER............................ 40

4. Static Modeling of Railway Concrete Sleeper 40

4.1. Dynamic modeling of concrete sleepers 40

4.2. Modeling of concrete sleepers for five (5) countries 41

4.2.1. Design rail seat load calculation 43

4.3. Finite element model... 44

4.4. Elements used for finite element 45

4.4.1. SOLID65 Element 45

4.4.2. LINK8 Element 45

4.5. Flexural performance requirements for prestressed mono-block designs according to AREMA standard for concrete sleeper ... 46
  4.5.1. Ballast pressure ... 46
  4.5.2. Bending moments ... 47
4.6. Rail seat and sleeper center positive and negative bending moment support location 48
4.7. Validation of finite element result ... 48
CHAPTER FIVE ... 51
FINITE ELEMENT RESULTS AND DISCUSION ... 51
5. Discussion ... 51
5.1. Stress results obtained according to ballast pressure distribution recommended by Chinese code of standard ... 51
  5.1.1. Stress result which produce maximum bending moment at rail seat ... 51
  5.1.2. Stress result which produce maximum bending moment at sleeper center ... 52
5.2. Static results according to ballast pressures recommended by each countries code 53
  5.2.1. Stress result which produce maximum bending moment at rail seat ... 53
  5.2.2. Stress result which produce maximum bending moment at sleeper center ... 54
  5.2.3. Dynamic results ... 56
CHAPTER SIX ... 57
CONCLUSION AND RECOMMENDATION ... 57
6. Conclusion ... 57
6.1. Recommendations ... 59
6.2. Future works ... 61
Reference ... 62

List of Figures

Figure 2.1: Arrangement of sleepers at different locations (iCivil Engineer) 6
Figure 2.2: Mono-block prestressed concrete sleeper (Profillidis, 1995) 9
Figure 2.3: Twin-block reinforced concrete sleeper (Profillidis, 1995).................................. 9
Figure 2.4: RS 115 Frame Sleeper (K. Riessberger, 2012) 10
Figure 2.5: Wide concrete sleeper (RAIL.ONE GmbH, 2004) 11
Figure 2.6: Variation of settlement with loading for wide sleeper and reference track (RAIL.ONE GmbH, 2004) 15
Figure 2. 7: Twin sleepers (RSN, 2004)... 15
Figure 2.8: Load Vs deflection curve of sleeper in static loading (Taherinezhad et.al. 2013) 16
Figure 2.9: Load-deflection curve for negative bending moment (Taherinezhad et.al. 2013) 17
Figure 3.1: Axle Load Distribution Factor (DF) (Committee CE-002, 2003) 21
Figure 3.2: Pressure Distribution (Committee CE-002, 2003)... 23
Figure 3.3: Factor k_v... 25
Figure 3.4: Design model for $M_{k,r,pos}$ 30
Figure 3.5: $M_{c, neg, 100}$ for standard gauge sleepers 32
Figure 3. 6: 3D view of B 70-2.4 concrete sleeper 34
Figure 3.7: Ballast support for maximum positive bending moment under the rail recommended by TB... 37
Figure 3.8: Ballast support for maximum negative bending moment at the middle of the sleeper recommended by TB 38
Figure3.9: Concrete Sleeper Production in process Ethiopia 39
Figure 4.1: Time history of dynamic rail seat load 41
Figure 4.2: 2-D view of prestressed concrete sleepers of four countries 42
Figure 4.3: Solid65 element geometry 45
Figure 4.4: Link8 element geometry... 45
Figure 5.1: Bending stress due to positive rail seat load 52
Figure 5.2: Bending stress due to sleeper center positive load... 53
Figure 5.3: Bending stress due to positive rail seat load 54
Figure 5.4: Bending stress due to negative sleeper center load 55
Figure 5.5: Deflection of concrete sleepers due to dynamic load... 56
Figure 6.1: Cross-section properties of recommended sleeper... 59
Figure 6.2: Stress which produce maximum bending moment at rail seat............................ 60
Figure 6.3: Stress which produce maximum bending moment at sleeper center 60

List of Tables

Table 2.1: Comparison of wide sleeper and B70 sleeper (RAIL.ONE GmbH, 2004)............ 12
Table 2.2: Types of wide sleepers used in conjunction with different types of track (RAIL.ONE GmbH, 2004)............ 13
Table 3.1: Concrete sleeper design dimensions (ARTC, 2013)............ 18
Table 3.2: Maximum permissible stress in the concrete (Committee CE-002, 2003)............ 19
Table 3.3: Maximum ballast pressure (Committee CE-002, 2003)............ 22
Table 3.4: Positive bending moment at the rail seat (Committee CE-002, 2003)............ 23
Table 3.5: Maximum positive bending moment at the center (Committee CE-002, 2003).... 24
Table 3.6: Typical values of k_d............ 28
Table 3.7: Recommended values for $k_{i,c}$ for, narrow gauge, standard gauge and broad gauge29
Table 3.8: K_p values............ 29
Table 3.9: Concrete sleepers used in Germany produced by Rail.one (RAIL.ONE GmbH, 2004)............ 33
Table 3.10: Dimension of B 70-2.4 concrete sleepers............ 34
Table 3.11: Geometric properties of prestressed concrete sleepers used in china............ 36
Table 4.1: Geometric parameters of prestressed concrete sleepers (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)............ 43
Table 4.2: Properties of concrete used for modeling (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)............ 43
Table 4.3: Properties of reinforcing tendons used for the modeling (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)............ 44
Table 4.4: Average ballast pressure............ 46
Table 4.5: Bending moment calculation (AREMA, 2010)............ 47
Table 4.6: Factored design positive and negative bending moment at the rail seat and at sleeper center............ 48
Table 4.7: Comparison of the FE result with the AREMA recommendations for both negative and positive values of bending moment at rail seat and sleeper center............ 49
Table 6.1: Geometric properties............ 59
Chart 1.1: The general procedures used to accomplish the thesis............ 3

Appendix

Appendix A: Section Properties of Prestressed Concrete Sleepers

Appendix B: Ballast Pressure Distribution Recommended by each Countries Standard

Appendix C: Typical Command used for the Construction of FE Model

Appendix D: Deflections according to AREMA Lab Setup

Figure D- 1: Deflection due to positive rail seat load

Figure D- 2: Deflection due to negative rail seat load

Figure D- 3: Deflection due to positive sleeper center load

Figure D- 4: Deflection due to negative sleeper center load

Appendix E: Stress Contour Plot results according to each Countries Ballast Pressure Distribution

Figure E1, E2, E3 and E4: Stress for maximum positive bending moment at rail seat

Figure E5, E6, E7 and E8: Stress for maximum negative bending moment at sleeper center

Appendix F: Stress Contour Plot results according to Chinese Ballast Pressure Distribution

Figure F1, F2, F3 and F4: Stress for maximum positive bending moment at rail seat

Figure F5, F6, F7 and F8: Stress for maximum negative bending moment at sleeper center

Notation

A = is the cross section of the sleeper, in millimeter^2

a = length of pressure distribution (ballast support) beneath each rail seat, in meters

a = is the sleeper spacing

$a1$ = length from edge of sleeper to center of rail seat

b_{rail} = is the width of the rail foot

b_1 = unsupported length of sleeper,

b' = pad width

C = bedding modulus

c = rail seat center spacing

c_{tot} = the total stiffness for one rail support

c_1 = the stiffness of rail pad for static load

c_2 = stiffness of ballasted and subsoil for one support

C_2 = the modulus elasticity for ballast and subgrade

DF = factor, in percent

E_c = young's modulus of a concrete, in gigapascal

E_R = the modulus of elasticity of rail

E_s = young's modulus for the rail steel, in megapascal

e = effective support length

e_p = is the eccentricity of the prestressing force, in millimeter

f_c' = the characteristic compressive strength of concrete required by the designer at 28 days, in megapascals

$f_{ct,fl,fat}$ = concrete flexural tensile strength after dynamic loads, in newton per millimeter^2

$f_{ct,fl,t28days}$ = concrete flexural tensile strength under static load at the age of 28 days, in newton per millimeter^2

g = distance between rail centers, in meters, at the head of the rail

I = second moment of area for the rail section, in metres^4

I_R = is the moment of inertia of the rail, in metres^4

j = combined quasistatic and dynamic design load factor

k = track modulus, in megapascals

k_d = factor used to determine the longitudinal load distribution

$k_{i,r}$ = factor for difference in bending moment under the rail seat

$k_{i,c}$ = factor for increase in bending moment at the rail seat

k_p = factor for attenuation of impact load by rail pads

k_r = factor to take in to account the variation of the sleeper reaction in the ballast due to longitudinal support fault along the track

k_t = factor for calculating static test bending moment

k_v = dynamic factor

k_1 = impact coefficient

k_{1d} = impact coefficient for dynamic test

k_{2d} = impact coefficient for dynamic test

k_2 = impact coefficient

k_3 = coefficient for fatigue test

L = length of sleeper at base, in meters

L_{el} = is elastic length of the Winkler beam

L_p = length of ballast pressure

Mc = center moment from loading effect

$M_{c,neg,100}$ = is the negative bending moment at the center of the sleeper

M_{C+} = maximum positive design bending moment at the mid-span (center) of the sleeper, in kilonewton meter

M_{C-} = maximum negative (design) bending moment at the mid-span (center) of the sleeper, in kilonewton meter

M_{dc} = bending moment at the center

M_{dcn} = negative bending moment at the center

M_{drn} = negative bending moment at the rail seat

M_{dr} = positive bending moment under the rail seat in kilonewton meter

$M_{k,r,pos}$ = the characteristic positive rail seat load

$M_{k,c,neg}$ = the characteristic negative bending moment at the center

$M_{k,c,pos}$ = the characteristic positive bending moment at center of sleeper

$[M_c]$ = maximum negative moment at the middle

Mg = rail seat moment

$[Mg]$ = maximum positive rail seat moment

M_k = characteristic moment

M_{R+} = maximum positive (design) moment at the rail seat, in kilo newton metres

M_{R-} = maximum negative (design) moment at the rail seat, in kilo newton metres

M_t = static test bending moment

$M_{t,c,pos}$ = sleeper the positive testing bending moment at sleeper center

$M_{t,c,neg}$ = sleeper the negative testing bending moment at sleeper center

$M_{t,r,pos}$ = sleeper rail seat positive testing bending moment

$N_{p(t=40years)}$ = is the remaining force of prestress after 40 years, in newton

P_{ab} = maximum ballast pressure, in kilopascals

P_k = normal dynamic rail seat load

P_o = unit rail seat load

Q = static wheel load, in kilonewtons

Q_o = unit wheel load

Q_x = the load carried by any sleeper, per rail, in kilonewtons

R = design rail seat load, in kilonewtons

R_d = the design rail seat load

s = sleeper spacing, in meters

v = speed of a locomotive, in meter per second

W = maximum load per unit length of sleeper, in kilonewton's per meter

W = is modulus of cross section, in milimeter^3

x = distance from the sleeper to the wheel load, in meters

x_i = axle position

y = width at intermediate bottom transition of sleeper

y_o = is deflection due to a unit wheel load

z_x = rail deflection at distance x from a point load, in millimeters

z = width at trapezoidal bottom transition of sleeper

η = factor for influence of axle position

λ = is lever length of resulting internal forces

σ_{cc} = compressive strength of a concrete, in mega Pascal

σ_{ct} = tensile strength of a concrete, in mega Pascal

$\Delta\sigma_{c,c+s+r,t}$ = 40years=is the loss of prestress in concrete after 40 years, in newton per millimeter^2

$\Delta\sigma_{c,c+s+r,t}$ = 28days=is the loss of prestress in concrete in 28 days, in newton per millimeter^2

λ $= \left(\frac{k}{4EI}\right)^{0.25}$ in metres^{-1}

ρ_c = density of concrete in kilogram per meter^3

ρ_s = density of tendon in kilogram per meter^3

υ_c = poison’s ratio of a concrete

υ_s = poison’s ratio of steel tendon

ξ_i $= \frac{x_i}{L_{el}}$

Acronyms

AREMA = American Railway Engineering and Maintenance-of-Way Association

FE = Finite element

FEM = Finite element method

RSN = Railway System Net

CHAPTER ONE

INTRODUCTION

1.1. Background

The idea of constructing a railway to link the Ethiopian capital with the coast appears to have been first conceived by Menelik's Swiss adviser, Alfred Ilg. After countless negotiations with Franc, the concession was reached on March 9, 1894 and the plan was to build the railway from coast, Djibouti, to Entoto via Harar and then to the White Nile via Kaffa. The Djibouti-Ethiopia railway (Chemin de Fer Djibouti-Ethiopien, or CDE) project consists of a 25-year railway operating concession for the 780 km railway running from Djibouti to Addis Ababa through Dire Dawa (Pankhurst, 2006).

The railway, constructed at the beginning of the 20th Century, has deteriorated due to lack of maintenance, poor management, and a lack of commercial focus. Consequently, the Addis-Assab road has become the primary trade transportation route for traffic from the capital to the port of Djibouti. Now Ethiopia has launched the construction of a 5,000 km railway network which aims to link the capital, Addis Ababa, to various regions of the country which is part of the country's five-year transformation plan (ERC, 2011).

Even though the government is now constructing of railway line in different part of the country which are connected to the capital city, Addis Ababa, the country has no standard to construct the railway line. In addition to this, the country is new for the construction of modern railway system and therefore it is compulsory to depend on other countries standard in order to accomplish the planned projects. The construction of light rail transit (LRT) and the Addis Ababa-Djibouti railway line are already started by Chinese contractors. As there is no any research done to prove or verify that Chinese sleepers standard is the best appropriate in terms of long term flexural performance, more research should be done to adopt a good performing sleeper for Ethiopian railway construction.

This thesis focuses on comparison of four countries concrete sleepers and selecting the best performing sleeper for Ethiopian railway track design. The countries which are selected for this research are based on long term experience in railway technology. In the present study, a general assessment of concrete sleepers from different countries is stated. Furthermore, the study showed modeling the concrete sleepers of each country using finite element analysis (FEM) software's ANSYS, analyzing under the same loading conditions and finally the results are interpreted. The validation of the finite element for concrete sleepers is done using AREMA standard.

1.2. Statement of the problem

The history of railway in Ethiopian was started in1897 where the construction of national railway started from Djibouti. Even though Ethiopian has long history in railway, to date, there is no specific and proposed railway design and construction standard. Due to this, the production of concrete sleepers used for current railway construction is based on Chinese standard since the construction is being built by Chinese contractors. As we all know there is no any research done to show that the Chinese concrete sleeper standard used in Ethiopia is the most appropriate one. One may ask that why we don't have to use other countries concrete sleepers standard that have long history in railway such as Germany, Australia, Sweden, and England etc. In addition, it is believed that the verification of this standard for the Ethiopian condition is very important in terms of cost, flexural performance, durability, safety and any other local factors. This thesis assesses four countries experience in the concrete sleepers. In addition the study verifies the current concrete sleeper standard used in Ethiopia by comparing it with three countries (German, British and Australia) concrete sleeper standards both under static and dynamic loading conditions.

1.3. Research methodology

This study can be categorized in to two parts namely assessment and modeling parts. The methods used for the two parts are listed below:

1. Assessment of five countries experience

During this assessment the author reviews different literatures, railway standards of different countries, data collection from recognized organizations for example ERC (Ethiopian Railway Corporation) and site visit.

2. Software modeling

In the study FEM analysis software's ANSYS V12.0 is used for the modeling purpose. The structural parameters used in the modeling are based on Ethiopian conditions. The analysis was done for each sleeper and the results are compared favorably with and good performing sleeper will be selected. The general procedure followed by the Author to accomplish the thesis is shown in Chart 1.1 below.

Methods and Procedures

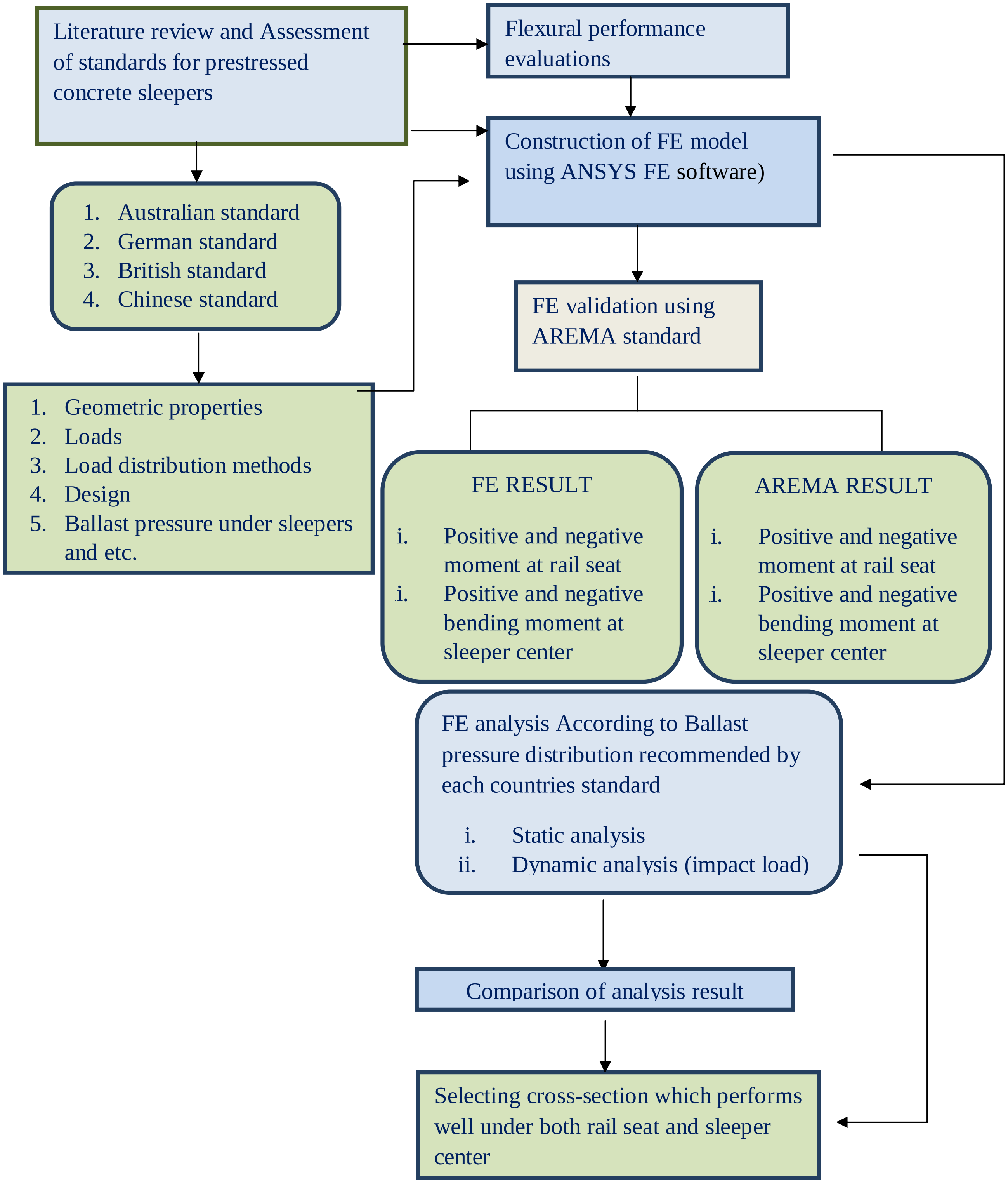


Chart 1.1: The general procedures used to accomplish the thesis

1.4. Scope of the Research

The study is limited to only conventional line and does not include light rail transit (LRT). The assessment and modeling are based on only five countries concrete sleeper experience which does not include other countries of the world.

1.5. Research objectives

The objective of the research can be divided into two parts

General objective and specific objective

a) General objective
- ✓ Comparing finite element analysis of four countries prestressed concrete sleepers and selection of cross-section for Ethiopian railway.

b) Specific objective
- ✓ Validation of finite element using AREMA standard.
- ✓ Comparing analysis result of five countries concrete sleepers in terms of flexural performance and selecting the best performing one and recommending for the case of Ethiopia.

CHAPTER TWO

LITERATURE REVIEW

2.1. Development of sleeper

Sleepers in railway track perform two important functions: (a) hold the track to gauge, and (b) transmit and distribute the oncoming loads to the ballast underneath (Mundrey, 2000).

In the past, sleepers for the railway track consisted of slabs of stones or longitudinal timbers laid continuously under the rail. With the revolution of better rail design, it was not considered necessary to give a continuous support to the rail (Mundrey, 2000). This leads to the adoption of cross sleepers, which were first introduced in Britain in 1835, and are now employed universally.

2.2. Ideal sleeper

An ideal sleeper should meet the following requirements (iCivil Engineer, 2002):

- ✓ Initial and maintenance cost should be minimum
- ✓ Its weight should be moderate to handle easily
- ✓ It should be able to absorb shocks and vibrations
- ✓ It should have sufficient bearing area
- ✓ Fixing and removing of fastening should be easy
- ✓ Should have long service life

2.3. Spacing of sleepers

Sleepers spacing provided on a particular railway line depend up on (Mundrey. 2000):

a) The strength of the rail
b) The type and density of sleeper materials
c) Depth of ballast layer
d) The bearing capacity of the formation and
e) The axle loads, volume and speed of traffic

Generally the spacing of sleepers is kept uniform throughout the length of the rail but near the joints it is kept less than usual. In Figure 2.1 shows that the spacing between joint sleepers, between joint sleeper and first shoulder sleeper, between first shoulder sleeper and second shoulder sleeper and between second shoulder sleeper and intermediate sleeper is different from each other and then the spacing is same between all the intermediate sleepers (iCivil Engineer, 2002).

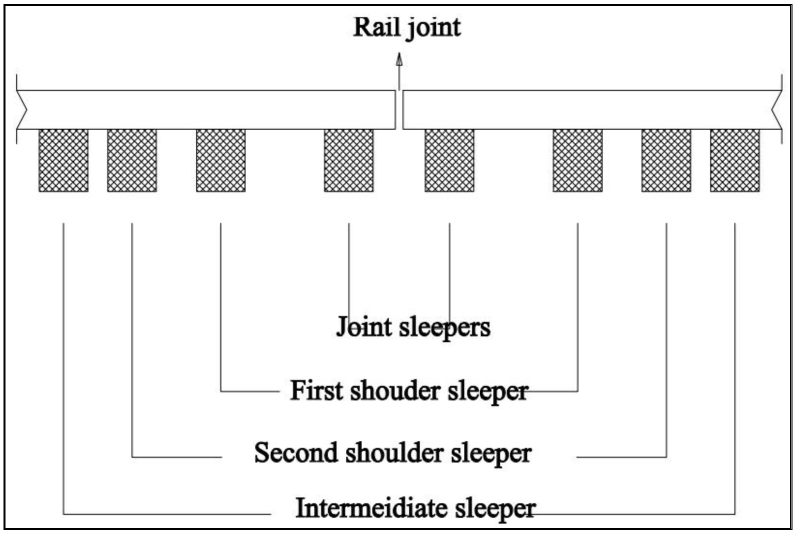


Figure 2.1: Arrangement of sleepers at different locations (iCivil Engineer)

2.4. Types of Sleeper

According to material aspects, sleeper can be classified as wooden, steel and reinforced concrete sleeper (Bernhard, 2005). The following few pages discuses about sleepers used in railway specially the different types of concrete sleepers as it is the main concern of this paper

2.4.1. Wooden Sleeper

Wooden sleeper is only suitable for low speed traffic lines with the speed limit of 160 km/h and below. Acceptable species of wood for this type of sleeper are European oak, beech, pine and etc. Nowadays in some countries, wooden sleeper is being replaced by concrete sleeper (Bernhard, 2005).

2.4.2. Steel Sleeper

In past times steel ties (sleepers) have suffered from poor design and increased traffic loads over their normal long service life. These aged and often obsolete designs limited load and speed capacity but can still, to this day, be found in many places globally and performing adequately despite decades of service. There are great numbers of steel ties with over 50 years of service which could be rehabilitated and continue to perform well (Bernhard, 2005).

2.4.3. Concrete Sleeper

Concrete sleepers have become more common mainly due to greater economy and better support of the rails under high speed and heavy traffic than wooden sleepers. Wood was the only material used for making sleepers especially in Europe in early rail way history due to this shortage of wood has occurred which increases the cost of wood. This makes the engineers to find an alternative to wood sleepers (RSN, 2004).

The following points are some of the advantage and dis advantage of concrete sleepers.

Advantages:

a) Do not rot like timber sleepers.
b) Extra weight makes track more stable, particularly with changes in temperature.
c) Unlike wooden sleepers, concrete sleepers do not expand under hot conditions causing tracks to buckle.
d) Withstand fire hazards better than wooden sleepers.
e) Longer life than wooden sleepers
f) Less maintenance activities and lower maintenance costs

Disadvantages:

a) When trains derail and the wheels hit the sleepers, timber sleepers tend to absorb the blow and remain intact, while concrete sleepers tend to shatter and have to be replaced.
b) Concrete sleepers are heavier and need stronger manpower and even special tools to carry them.
c) Gives more resistivity to the track.
d) Cost more, especially initial cost.

Below are the different types of concrete sleepers:

2.4.3.1. Prestressed concrete mono-block sleepers

After the Second World War, prestressed concrete was developed and used extensively on new structures (Bonnett, 1996). Figure 2.2 shows the mono-block sleepers used in German and British railways.

Concrete mono-block sleepers (Profillidis, 1995):

- ✓ Offers a reduced sleeper height at the central part;
- ✓ Allows reduction of the reinforcement used, in comparison to the twin-block sleeper;
- ✓ Generally, it is not heavier compared to the twin-block sleepers.

Mundrey (2000) and Bonnett (1996) stated the advantage and disadvantage of mono-block concrete sleeper as follows:

Advantage

- ✓ The great advantage of prestressed concrete is that it can be kept under compression when subjected to all conditions of flexure, both under load and after. This means that tension cracks do not occur which can allow ingress of moisture and corrosion of the embedded steel bar.
- ✓ Heavy weight of the concrete lend stability to the tack;
- ✓ Provides good longitudinal and lateral resistance;
- ✓ Flat bottom of mono-block sleepers makes modern method of track maintenance simple and possible.
- ✓ Either inflammable or vulnerable to termite or corrosion due to this it has long life.
- ✓ Provides better safeguard for all track parameter, viz. gauge, cross-level, twist, alignment, longitudinal level and unevenness.

Disadvantage

- ✓ Manufacturing of concrete sleepers, their transport, lying and maintenance requires superior technology;
- ✓ The manufacturing plants generally have a heavy initial cost;
- ✓ Difficulty in handling, lying and maintenance due to their heavy weight;
- ✓ Excessive damage during derailment.

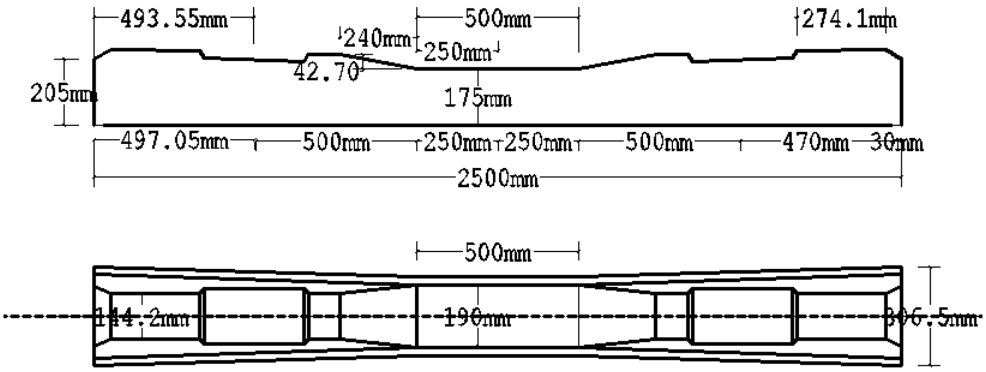


Figure 2.2: Mono-block prestressed concrete sleeper (Profillidis, 1995)

2.4.3.2. Twin block sleepers

The twin block sleeper consists of two reinforced concrete blocks joined together with a steel tie bar cast into the blocks Figure 2.3. The standard sleeper weighs 230 kg which is less than the mono-block equivalent, however handling and placing can be difficult due to the tendency to twist when lifted. Twin block sleepers can be provided with resilient 'boots' and can be incorporated into non-ballasted slab track or monolithic embedment in road surfaces for light rail street running (Bonnett, 1996).

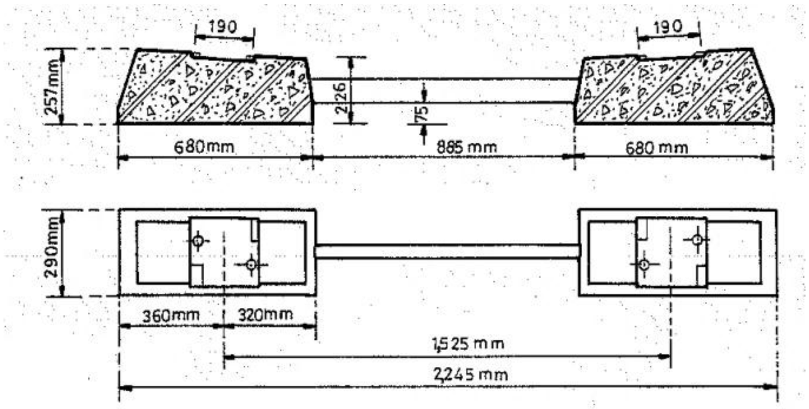


Figure 2.3: Twin-block reinforced concrete sleeper (Profillidis, 1995)

The advantage and disadvantage of twin-block concrete sleeper as stated are listed below (Profillidis, 1995)

Advantage

- ✓ Due to its great weight, the twin-block sleeper provides very satisfactory transverse track resistance and high trail speeds;
- ✓ It keeps track gauge within satisfactory tolerances and has a long lifetime;
- ✓ Can be produced in each country;
- ✓ Less expensive than timber sleepers.

Disadvantage

- ✓ Less satisfactory when the ballast does not have the suitable thickness and mechanical characteristics;
- ✓ Load distribution and flexibility are less satisfactory with twin-block than with timber sleepers;
- ✓ Requires elastic fastenings and because of their great weight, handling is difficult;
- ✓ The twin-block sleeper (in contrast to the timber sleeper) requires special accessories, so as to ensure the necessary insulation for signaling and electric traction operation;
- ✓ Special attention should be given to the behavior of the tie bar

2.4.3.3. Frame sleeper

Framed sleepers transmit loads by a girder-grid, by combining a continuous longitudinal beam with cross members. The “longitudinal beams” is formed by sections in the frames and these sections are connected and held in place by rail and the fastenings. Framed sleepers transmit the wheel load in a continuous manner onto the ballast bed and reduce the pressure under the sleeper substantially (Esveld, 2001).

Figure 2.4: RS 115 Frame Sleeper (K. Riessberger, 2012)

The double H-shaped concrete sleeper (Figure 2.4) was tested in Austria. These elements can be considered as two sleepers which are connected at the fastening systems with 'bridges'.

The same principle as with the wide sleeper is used to increase the bearing surface of the sleeper and, thus, decrease the pressure on the ballast. The elements are 2.4 m long and 0.95 m wide with two sets of rail fastenings per element. Between the fastening systems, the rail itself is supported by the concrete bridge which provides a quasi-continuous rail support. Underneath the sleeper elements a 12 mm thick polymer layer will provide a better spreading of the loading and additional damping. Test results showed a reduction in settlements of two-thirds compared to a normal sleeper (K.Riessberger, 20012).

Advantages of frame sleeper system over conventional cross tie sleepers are (RSN, 2004):

- ✓ Reduced ballast pressure (up to half percent)
- ✓ Increased lateral resistance
- ✓ Full frame stiffness
- ✓ Fit for curves with all radii and ramps;

2.4.3.4. Wide Sleepers

Wider concrete mono-block sleepers can be produced with a size of 57 cm and no ballast between the sleepers. These sleepers are developed in Germany by RAIL.ONE GmbH Company as an alternative to classic concrete sleepers (RAIL.ONE GmbH, 2004).As indicated in RSN (2004) the new form of superstructure with wide sleeper technology is very suitable for carrying higher axle loads (25 t axle), causes a considerable reduction in pressure on the ballast and stress on the substructure. Additionally rolling of railway materials (ballast) to the surrounding area is reduced and maintenance intervals and life period are prolonged. The wide sleeper is used in long-distance regional traffic for speeds up to and beyond 200 km/h. The system is suitable for all gauges as well as tilting train technology, passenger and goods trains with high axle loads. Figure 2.6shows below typical wide sleeper type.

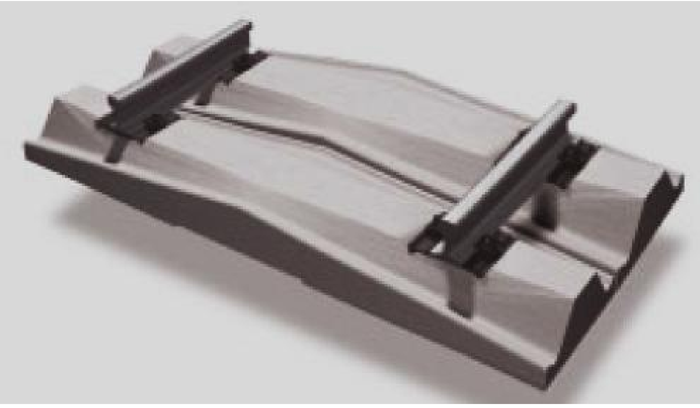


Figure 2.5: Wide concrete sleeper (RAIL.ONE GmbH, 2004)

RAIL.ONE GmbH (2004) compared wide sleeper with the B70 mono-block sleepers and found that except the geometric data of the track, i.e. height, gauge and supporting points, only the weight, width and length were altered. During the laying of the sleepers a 3 cm gap is left when the distance between the sleepers is on average 60cm. Water and dirt materials can be prevented from infiltrating into the track beds by sealing the gaps with an elastic cover. The reduction in moisture infiltration due to the sealing of the ballast materials has a great role on the general stability of the rail track (RAIL ONE GmbH, 2004).Table 2.1 describes the size of wide sleeper and B70.

Table 2.1: Comparison of wide sleeper and B70 sleeper (RAIL.ONE GmbH, 2004)

Criterion	**B 70 W**	**BBS 1**	**Differences**
Sleeper length in m	2.6	2.40	- 0.20 m
Sleeper width in m	0.3	0.57	+ 0.27 m
Supporting surface in cm^2	5,700	10,260	+ 80 %
Sleeper head area in cm^2	570	830	+ 45 %
Dead weight in kg	320	560	+ 75 %

RAIL.ONE GmbH company developed different types of wide sleepers for different type of track. As indicated in RAIL.ONE GmbH (2004) the different types of wide sleepers used in conjunction with different types of track are summarized in the table 2.1 bellow.

Table 2.2: Types of wide sleepers used in conjunction with different types of track (RAIL.ONE GmbH, 2004)

Nomenclature of wide sleeper	Place of application	Description
BBS-SchO (BBS1 standard wide concrete sleeper **)**	Ballasted track	✓ used on most high performance track lines with speeds up to and greater than 200 km/h and high axle loads; ✓ low maintenance requirements as well as a high degree of railway line availability; ✓ meet both the high requirements of the tilting train technology and those of eddy current brakes;
BBS-FF (BBS 3 wide concrete sleepers**)**	Asphalt track	✓ are an optimal solution for high speed traffic; ✓ The heavy unloaded weight ensures increased transverse and longitudinal resistance to displacement as well as improved position stability to resist lifting forces; ✓ The thickness of the asphalt layer can be reduced to a minimum dimension of 15 cm.
BBS-BÜ	For railway crossing	✓ Reduce maintenance cost lost at crossing; ✓ large-surfaced sleeper surface simplifies the geometry of the road covering layers; ✓ The manufacturing costs are reduced correspondingly.
BBS-SO (Wide concrete sleepers with elastic sleeper	Ballasted track	✓ Sleepers with elastic sole pads additionally protect the track ballast and prolongs the useful life accordingly; ✓ They also bring about a considerable reduction in noise emission and transfer of secondary airborne noise.

Advantages of wide concrete sleepers are discussed below (RAIL.ONE GmbH, 2004)

a) Installation and maintenance:
   - ✓ The wide sleeper is laid by means of conventional track construction technology.
   - ✓ Tamping is performed with slightly modified machine technology.
   - ✓ The use of wide sleepers considerably prolongs the maintenance and tamping intervals.
   - ✓ The closed sleeper simplifies surface cleaning in the area of the railway station.
   - ✓ The reduced maintenance costs have a positive effect on the life cycle.

b) Reliability:
- ✓ A larger sleeper bedding area reduces the major fluctuations in support conditions experienced with conventional ballast track.
- ✓ The quality and stability of the position of a track just installed is retained for a longtime.
- ✓ The transverse resistances to displacement values are up to 70% higher.

c) Reduced wear on the ballast bed:
- ✓ High mass and continuous support in the ballast bed increases the stability of the track position.

d) Water protection
- ✓ Surface water and other fluids can be drained off selectively.
- ✓ Oils and lubricating fluids that must be disposed of at locomotive sidings are directed into lateral drainage channels and completely away from the subsoil.

e) Vegetation control
- ✓ Owing to the closed sleeper area, vegetation control on the track is considerably simplified – undesirable plant growth between the sleepers is virtually impossible.

f) Noise and Vibration
- ✓ Tests carried out so far have shown significant reduction in disturbance from secondary airborne noise.

Experimental test was made on track with wide sleeper supper structure on two projects. The first was the test track section and the second is the pilot project covering 12km. For the test section the route was loaded with a heavy traffic i.e. mixed traffic, $V \leq 60$ km/hr and axle load of up to 22.5 tonne. The pilot project was installed alongside a standard reference track. The track position was measured at regular interval for both cases. In addition the track with a wide sleeper showed a small settlement when compared to reference track (RAIL.ONE GmbH, 2004). Figure 2.7 below shows the settlement comparison of track with wide sleeper and reference track.

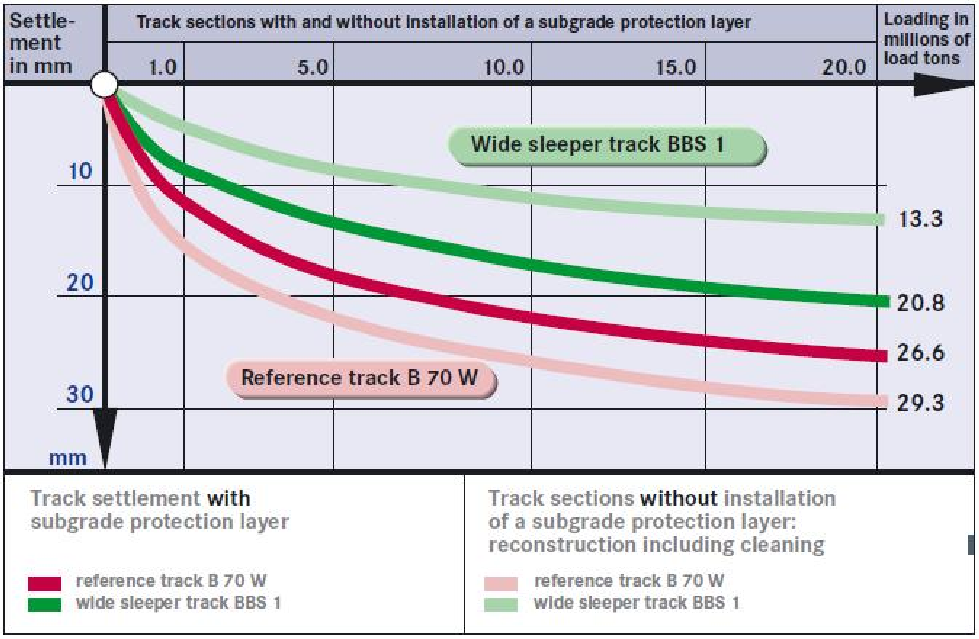


Figure 2.6: Variation of settlement with loading for wide sleeper and reference track (RAIL.ONE GmbH, 2004)

2.4.3.5. Twin Sleepers

The ZSX twin sleeper is made of a pair of two pre-stressed concrete sleepers which are connected by four steel rods longitudinally. This types of sleeper is manufactured by Leonhard Moll and Betonwerke GmbH and Co KG is recommended for regions with sharp curves, track subjected to temperature stress, bridges and transition track between traditional track and slab track or bridges. Twin sleepers are also available with elastic footing for ballast pressure reduction, increase of super structure flexibility and structure noise reduction (RSN, 2004).

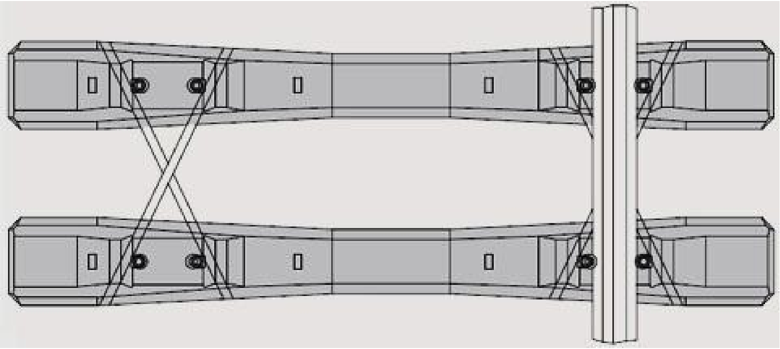


Figure 2. 7: Twin sleepers (RSN, 2004)

2.5. Factors affecting the performance of concrete sleepers

2.5.1. Cracking and Failure at Rail Seat

Taherinezhad et.al.(2013) reported that the rail seat positive bending moment is one of the main criteria in prestressed concrete sleepers design and which can lead to flexural cracks initiating from the bottom of the sleeper and propagating upward. The report described a series of rail seat positive bending using static and impact tests was carried out by researchers to explore the influence of support conditions and loading rates on the cracking mode of prestressed concrete sleepers (PCS). The sleeper was subjected to rail seat static bending test until complete failure occurred. The result showed that flexural crack, flexural-shear cracks and shear cracks were appeared at the bottom of the sleeper around the rail seat due to load of about 355 kN, 489 kN and 613 kN, respectively, as shown in Figure 2.8. In addition, some slip of pretensioning wires, large deflections and crushing of the concrete on the upper surface were observed.

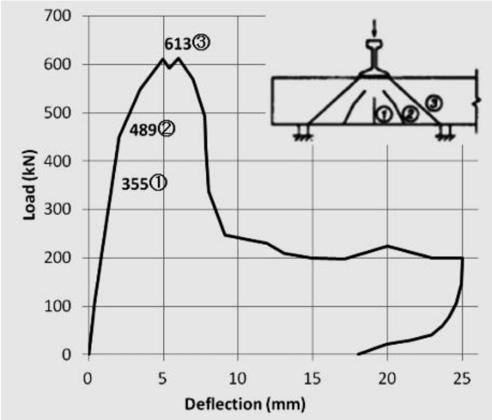


Figure 2.8: Load Vs deflection curve of sleeper in static loading (Taherinezhad et.al. 2013)

The impact loading has been carried out using an impact machine with a drop height of 1.52 m and two masses of 345 kg and 504 kg (corrected impact velocity of 5.22 m/s). They showed that, the concrete failed by shear diagonal crushing and spalling without any appreciable deflection warning. No yielding or damage in pretensioning wires was observed (Taherinezhad, et.al, 2013).

2.5.2. Cracking and Failure at Mid-span

One failure mode of PCSs is cracking at the top of mid span which occurs as a result of mid span negative bending moment. Kaewunruen and Remennikov (2006) performed an experiment in order to investigate the rotational capacity of prestressed concrete sleepers using mid span bending test and reported crack initiations and the ultimate loads of the sleepers. The first flexural crack were observed at a load of around 75kN and the sleeper damaged at a load of 133.3kN, equivalent to a bending moment of 45kN-m as shown in Figure 2.9 (Taherinezhad et.al..2013).

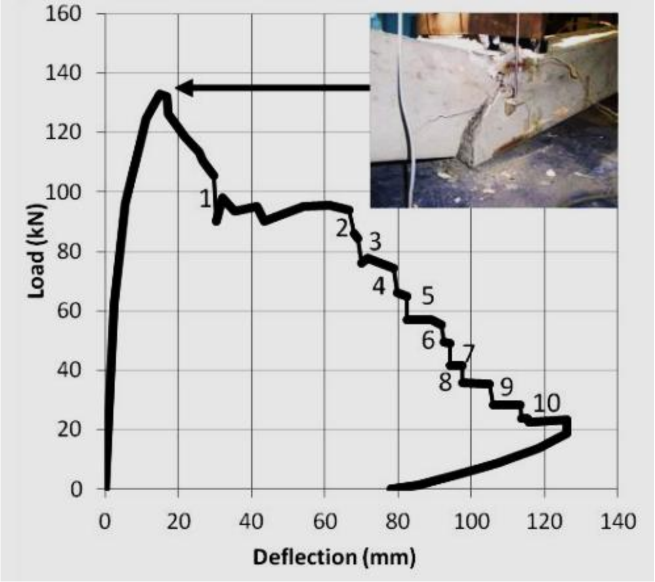


Figure 2.9: Load-deflection curve for negative bending moment (Taherinezhad et.al. 2013)

2.5.3. Concrete deterioration

Concrete deterioration is one of the most common failure mechanisms of concrete sleepers. In north America, the failure of concrete sleepers is highly caused by the deterioration of concrete due to low concrete strength; low prestress force; high curing temperature; reactive aggregates; fines intrusion; moisture intrusion; low abrasion resistance (concrete); poor pore system in cement; prestress diameter too large; too much steel in the cross-section; pad too soft; pad too hard; pad geometry creates high hydraulic pressures; pad stiffness changes too much over time (Zeman et.al., 2007).

Researchers investigated that there are so many types of problems which affect the performance of concrete sleepers. The most common problems are explained in the above topics and addressing all types of factors which influence the performance of concrete sleepers are beyond the scope of this thesis.

CHAPTER THREE

ASSESSMENT OF STANDARDS FOR CONCRETE SLEEPERS

In this thesis the selected five countries experience on concrete sleepers will be assessed. The assessment includes the concrete sleeper's code of standards used in each country, the dimensions of the sleepers with change in the axel load and the design methods used.

3. Australian railway concrete sleepers standard

The Australian railway prestressed concrete sleeper design and manufacturing is in accordance with the Australian standard (AS 1085.14) and Australian railway Track Corporation (ARTC) design specifications. The sleepers which are included in Part 14 of AS 1085 are mono-block pretension concrete sleepers with resilient fastenings and insulators. As indicated in ARTC there are two methods of sleepers design (ARTC, 2013). These are:

1. Heavy Duty: - are suitable for 30 tone axle loads.
2. Medium Duty: - for general use with axle loads up to 25 tone axle loads.

The code (AS 1085.14) covers different sections starting from the material requirement to designing and testing of prestressed concrete sleepers. In this thesis some parts of the codes are covered which are related to the objective of the research as shown in the following few pages.

3.1. Sleepers type and dimension according to ARTC

According to ARTC, concrete sleepers should preferably be designed to conform to the dimensions shown in Table 3.1

Table 3.1: Concrete sleeper design dimensions (ARTC, 2013)

Parameter	Heavy Duty Sleeper	Medium Duty Sleeper
Length	2440 - 2500mm	2440 - 2500mm
Width (at base)	245 - 255 mm	220 - 255mm
Depth (center of rail seat)	250mm maximum	250 mm maximum
Rail seat area (flat surface)	160mm x 180mm	160mm x 180mm
Rail pad size	160mm x 180mm x (7mm +/- 0.5mm)	160mm x 180mm x (7mm +/- 0.5mm)

3.2. Material requirement

The Australian standard AS 1085 part 14 includes the following materials for the production of concrete sleepers (Committee CE-002, 2003).

a) Cement
b) Aggregates
c) Tendon wires

According to Committee CE-002 (2003) the maximum amount of tendon diameter provided is 8mm unless specified by the purchaser. Strand tendons are stress-relieved 7-wire strand not larger than 10 mm diameter.

d) Concrete

The characteristic compressive strength (f_c') and minimum compressive strength at transfer (f_{cp}) of a concrete according to AS 1085 part 14 should no less than 50MPa and 30MPa respectively.

3.3. Design of Sleepers

The sleepers used for the design are of prestressed concrete sleepers with center to center spacing of sleepers of 500 mm to 750 mm. The sleepers are designed as fully prestressed sections where the limiting stresses are based on the fatigue resistance of the concrete (Committee CE-002, 2003). The limiting stresses are shown in Table 3.2.

Table 3.2: Maximum permissible stress in the concrete (Committee CE-002, 2003)

Type of stress	Maximum permissible stress
Compression	$0.45f_c'$
Tension (flexure)	$0.4(f_c')^{0.5}$

The depth and width of the sleeper may vary throughout its length. The minimum length of the sleeper is determined by the bond development requirements of the prestressing tendons, and the base width shall then be determined by the allowable bearing pressure (Committee CE-002, 2003).

3.3.1. Design Forces (vertical wheel load)

According to AS 1085.14 three types of loads are considered in design of concrete sleepers.

a) Quasistatic load

The quasistatic load is the sum of the static load and the effect of the static load at speed. It includes the effects of the geometrical roughness of the track on vehicle response and the effect of unbalanced super elevation (Committee CE-002, 2003). Typical values of quasistatic loads are 1.4 to1.6 times the static wheel load prior to the inclusion of unbalanced super elevation effects.

b) Dynamic load

The dynamic load is the load due to high frequency effects of the wheel/rail load interaction and track component response. A minimum allowance of 150 percent of static wheel load shall be used (Committee CE-002, 2003).

c) Combined vertical design load factor (j)

The combined quasistatic and dynamic design load is the sum of the static load, the allowance for the effects of the static load at speed and the allowance for dynamic effects (Committee CE-002, 2003: 19). As stated in AS 1085.14 the combined quasistatic and dynamic design load shall not be less than 2.5 times the static wheel load.

3.3.2. Load distribution on the sleeper

According to AS 1085.14 for a given sleeper spacing, the actual proportion of the vertical axle load taken by an individual sleeper shall be obtained from Figure 3.1. The distribution factors (DF) adopted in Figure 3.1 is based on rails equal to or heavier than 47 kg/m (Committee CE-002, 2003).

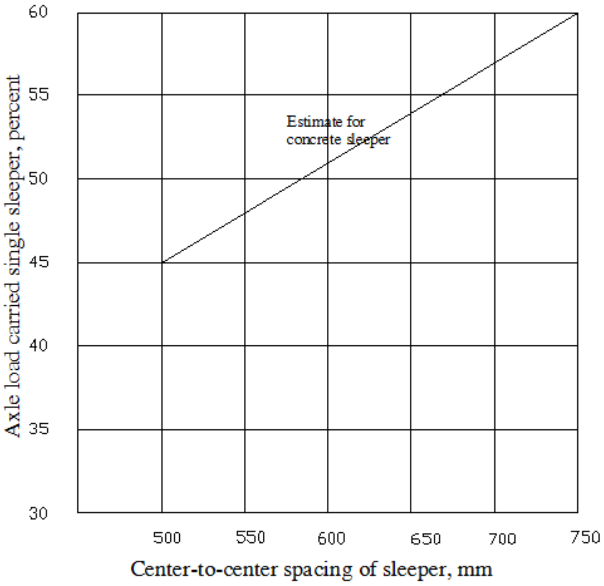


Figure 3.1: Axle Load Distribution Factor (DF) (Committee CE-002, 2003)

The proportion of vertical load taken by a single sleeper resulting from a single wheel may be determined from the following equation (Committee CE-002, 2003: 18):

$$Q_x = (k \times z_x)s = \frac{\lambda s Q}{2} e^{-\lambda x}(\cos\lambda x + \sin\lambda x) \qquad (3.1)$$

Where

Q_x = the load carried by any sleeper, per rail, in kN, for a single wheel at a distance x

x = distance from the sleeper to the wheel load, in meters

Z_x = rail deflection at a distance x from a point load

s = sleeper spacing, in meters

Q = static wheel load, in kilonewtons

$\lambda = \left[\frac{k}{4EI}\right]^{0.25}$

k = track modulus, in MPa

E = young's modulus for the rail steel, in MPa

I = second moment of area for the rail section, in m^4

3.3.3. Rail seat load

According to **AS 1085.14** the rail seat load (R) is based on the impact and load distribution factors determined in accordance with section 3.3.1 and 3.3.2 discussed above (Committee CE-002, 2003: 18). The rail seat load is calculated as follows:

$$R = j \times Q \times \frac{DF}{100} \tag{3.2}$$

where

j= combined quasistatic and dynamic design load factor

Q= static wheel load, in kN

DF= distribution factor, in percent

3.3.4. Ballast and ballast pressure

The maximum ballast pressure is determined from loading conditions similar to those for the maximum positive bending moment at the rail seat. The maximum ballast pressure (p_{ab}) as indicated in AS 1085.14is based on uniform pressure distribution beneath each rail seat and is calculated using the equation shown in Table 3.3 (Committee CE-002, 2003).

Table 3.3: Maximum ballast pressure (Committee CE-002, 2003)

Distance between rail centers (g)	Length of ballast support beneath each rail seat	Equation for maximum ballast pressure (p_{ab})
g > 1.5 m (standard and broad gauge)	a = L − g	$p_{ab} = \frac{R}{b(L-g)}$
1.5 m > g > 1.0 m (narrow gauge)	a = 0.8 (L -g)	$p_{ab} = \frac{R}{0.8b(L-g)}$

The ballast pressure does not exceed 750 kPa for high quality, abrasion-resistant ballast. If lower quality ballast materials are used, the allowable ballast pressure is reduced accordingly (Committee CE-002, 2003).

3.3.5. Design moment

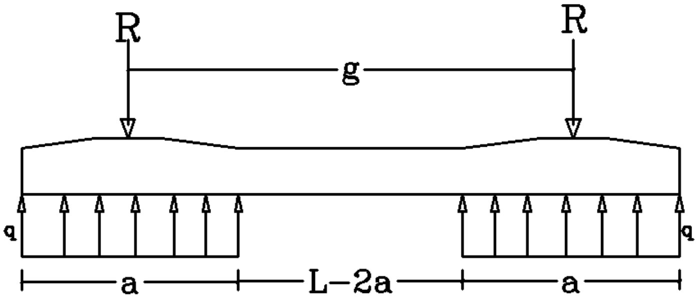
3.3.5.1. Moment at the rail seat

The maximum bending moment which occurs at the rail seat produces a compressive stress at the top and tensile stress at the underside of the sleeper. The value of this moment, the rail seat positive design bending moment (M_{R+}), is based on a uniform ballast support beneath each rail seat as shown in Figure 3.2(a) (Committee CE-002, 2003). The maximum positive bending moment at the rail seat is shown in the Table 3.4 below.

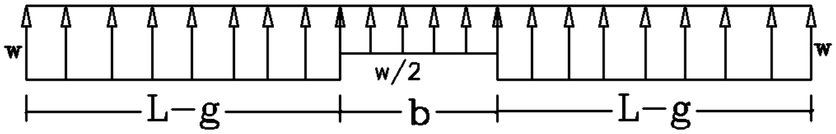
Table 3.4: Positive bending moment at the rail seat (Committee CE-002, 2003)

Distance between rail centers (g) in m	Length of ballast support beneath each rail seat (a) (m)	Maximum positive bending moment at rail seat (M_{R+}) (kNm)
g > 1.5 m (standard and broad gauge)	L − g	R (L − g)/8
1.5 m > g > 1.0 m (narrow gauge)	0.8 (L − g)	R (L − g)/6.4

As explained in AS 1085.14the rail seat negative design bending moment (M_{R-}) should not be less than 67 percent of the rail seat positive design bending moment or 14 kNm, whichever is greater (Committee CE-002, 2003).



a) Pressure distribution for maximum positive rail seat and center moments



b) Pressure distribution for maximum center moment (negative) for track gauge of 1600mm and greater

Figure 3.2: Pressure Distribution (Committee CE-002, 2003)

3.3.5.2. Moment at center

The maximum positive bending moment of the sleeper is based on a pressure distribution beneath each rail seat, similar to that shown in Figure 3.2(a) (Committee CE-002, 2003). The length of the ballast pressure distribution beneath each rail seat and the center positive design bending moment (M_{C+}) is shown in Table 3.5 below.

Table 3.5: Maximum positive bending moment at the center (Committee CE-002, 2003)

Distance between rail centers (g) in m	Length of ballast support beneath each rail seat (a) (m)	Maximum positive bending moment at the center (M_{C+}) (kNm)
g > 1.5m (standard and broad gauge)	0.9(L − g)	0.05R (L − g)
1.5 m > g > 1.0 m (narrow gauge)	0.8 (L − g)	0.05R (L − g)

The maximum negative bending moment is taken to occur at the center of the sleeper, producing tensile stress at the top and compressive stress at the underside of the sleeper (Committee CE-002, 2003). The value of the center negative design bending moment (M_{C-}) for track gauge of 1600 mm and greater is based on a ballast pressure distribution as shown in Figure 3.2(b) and is calculated as follows:

$$M_{C-} = 0.5\left[R \times g - \left(W \times g\left(L - g\right) - \frac{W\left(2g - L\right)^2}{8}\right)\right] \tag{3.3}$$

where,

$$W = \frac{4R}{\left(3L - 2g\right)} \tag{3.4}$$

The value of the maximum center negative bending moment (M_{C-}) for track gauge of 1435 mm is based on a uniform distribution of ballast pressure on the sleeper soffit and is calculated as follows(Committee CE-002, 2003):

$$M_{C-} = \frac{R\left(2g - L\right)}{4} \tag{3.5}$$

3.4. British railway concrete sleepers standard

The European standard of concrete sleeper (EN 13230) is prepared by the CEN member who constitutes most part of European countries like German, British, Norway, Sweden and etc. (EN 13230-1, 2009).

Since British is one member of CEN the design of concrete sleeper used in British are adopted from European standard EN 13230.

3.4.1. Material requirement of concrete sleepers

As stated in (BS EN 13230-6, 2014) the materials for the productions of concrete sleepers should comply with the European standard. The lists of materials used in (BS EN 13230-6, 2014) are listed below.

a) Cement:- Portland cement type CEM 1 with minimum strength-grade class 42.5
b) Aggregate
c) Wire tendons
d) Concrete: - the minimum compressive strength is not less than 55MPa.

3.4.2. Loads

Curving loads: are loads which are formed due cant deficiency or excess lateral force of the wheel in the curve. These forces can be taken into account as a dynamic rail seat load in the design of prestressed mono-block sleepers in the following ways:

- ✓ The quasi-static increase of vertical wheel load on rails due to cant deficiency or excess;
- ✓ The lateral force of wheel which can also induce an additional bending moment.

Both effects can be included in normal service dynamic factor k_v. The values of normal service factor k_v is shown in the figure 3.3 bellow.

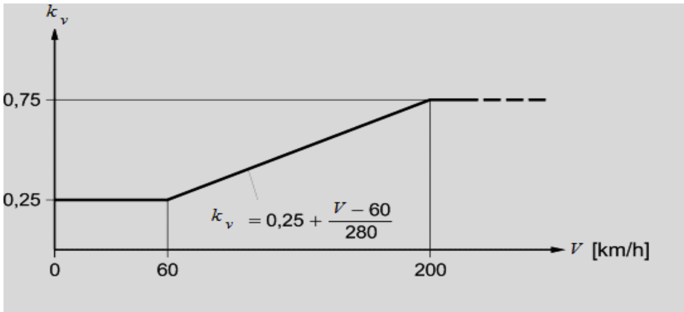


Figure 3.3: Factor k_v

The factor k_v has been derived from measurement in track with usual leveling defects and depressions. For a track with a high maintenance level (e.g. high speed lines) lower values of k_v may occur.

3.4.3. Method of bending moment determination

The determination of bending moment in sleepers laid on ballast track for the service stage is determined using two methods, namely empirical and theoretical method (BS EN 13230-6, 2014).

Empirical method is a method in which the sleepers are tasted in the track under service conditions. Deficiencies during taste are excluded through step wise improvement and the confirmation of the taste result is done after a minimum of five year permanent observation. The characteristic bending moment is determined by measurement in the track (BS EN 13230-6, 2014).

Theoretical method considers the dynamic load, the elastic behaviour of all track components including all types of elastic pads and the variable ballast-subsoil elasticity and the different ballast consolidation phases.

3.4.4. Cracks in concrete sleepers

1. Cracks under rail seat: - under the rail seat there are three moments that should be defined. These are static testing bending moment, exceptional loading bending moment and ultimate bending moment (BS EN 13230-6, 2014).
    - ✓ Static testing bending moment: - caused when the sleeper is subjected to static load and crack is not allowed at the tensile face of the prestressed concrete sleeper.
    - ✓ Exceptional bending moment: - caused due to exceptional and random impact loads and is calculated by multiplying the positive characteristic bending moment $M_{k,r,pos}$ by coefficient k_1 and any crack at this stage will close.
    - ✓ Ultimate bending moment: - caused due to accidental impacts, calculated by multiplying the positive characteristic bending moment $M_{k,r,pos}$ by coefficient k_2.

4. Cracks at center part (prestressed mono-block sleepers): - flexural bending moment in the central part of the sleeper is induced by the dynamic rail seat load and depends on the distribution of the ballast reaction and crack is not allowed (BS EN 13230-6, 2014).

3.4.5. Distribution of longitudinal load

The distribution of the wheel load between sleepers along the track depends on:

- ✓ The vertical stiffness of the rail,

- ✓ Sleeper spacing,
- ✓ Rail pad stiffness and the stiffness of ballast or platform.

According to BS EN 13230-6 there are two factors which are used to determine the longitudinal distribution of axle load on the sleeper. These are k_d factor used to determine the longitudinal load distribution and k_r to take in to account the variation of the sleeper reaction in the ballast due to longitudinal support fault along the track (BS EN 13230-6, 2014). The load distribution factor k_d can be calculated using Equation 3.6.

$$k_d = \frac{P_o}{Q_o} \tag{3.6}$$

where,

P_o = unit rail seat load and is given by

$$P_o = c_{tot} \times \sum_1 \eta_i \times y_o \text{ in N} \tag{3.7}$$

c_{tot} = is the total stiffness for one rail support and is given by

$$c_{tot} = \left(\frac{1}{c_1} + \frac{1}{c_2}\right)^{-1} \text{ in N/mm} \tag{3.8}$$

where,

c_1 = is the stiffness of the rail pad for static loads, in N/mm

c_2 = is the stiffness of ballast and sub soil for one support (half a sleeper)

$$c_2 = 0.5 \times A_R \times C_2 \text{ in N/mm} \tag{3.9}$$

where,

A_R = is the bearing area of sleeper, in mm^2

C_2 = is the modulus of elasticity for ballast and subgrade, in N/mm^3

η_i = is a factor for the influence of axle position x_i

$$\eta_i = \frac{\sin \xi i + \cos \xi i}{e^{\xi i}} \tag{3.10}$$

where,

$$\xi_i = \frac{x_i}{L_{el}} \tag{3.11}$$

L_{el} = is elastic length of the Winkler beam and given by

$$L_{el} = \sqrt[4]{\frac{4 \times E_R \times I_R}{c_{tot} / a}} \tag{3.12}$$

where,

E_R=is the modulus of elasticity of the rail, in N/mm^2

I_R=is the moment of inertia of the rail, in mm^4

a =is the sleeper spacing, in mm

y_o=is the deflection for a unit wheel load Q_o

$$y_o = \frac{Q_o \times a}{2 \times c_{tot} \times L_{el}} \text{ in mm} \tag{3.13}$$

Recommended values of k_d according to BS EN 13230-6:

a) For normal cases, k_d=0.5 may be used for rails ≥ 46kg/m and a sleepers spacing ≤ 65 cm with typical formation conditions.

b) For tracks with heavier rails and "low attenuation" rail pads, sleeper spacing of 0,6 m, sleeper length from 2,3 to 2,6 m, bedding modulus of C = 0,1 N/mm^3, single wheel or bogies, calculation of k_d using “beam on elastic foundation” theory leads to values as detailed in Table 3.6.

Table 3.6: Typical values of k_d

Rail type	**Rail weight (kg/m)**	**k_d**
49 E1	49	0.41
54 E3	54	0.40
60 E1	60	0.38

The value of k_r recommended by BS EN 13230-6 is 1.35.

3.4.6. Distribution of ballast reaction along the length of the sleeper

Variation of ballast reaction under the sleeper can be caused by:

- ✓ Characteristics of sub grade under ballast;
- ✓ Variation of ballast stiffness due to tamping or freezing;
- ✓ Ballast quality (size of ballast, stone characteristics and fouling of ballast layer).

The assumption that the ballast reaction under the sleeper is uniform creates change in load distribution in the track due to random formation of local load contact points within the ballast. As a result the values of bending moment obtained from this assumption and measurement in the track is different (BS EN 13230-6, 2014). Therefore the difference in bending moment can be taken into account by factors $k_{i,r}$ for bending moment at rail seat section or $k_{i,c}$ for bending moment increase at the center as shown in Table 3.7.

Table 3.7: Recommended values for $k_{i,c}$ for, narrow gauge, standard gauge and broad gauge

Country	**Narrow gauge**		**Standard gauge**		**Broad gauge**	
	Length	$\mathbf{k_{i\,c}}$	**Length**	$\mathbf{k_{i\,c}}$	**Length**	$\mathbf{k_{i\,c}}$
Germany			2.60	2.0		
			2.40	1.5		
British			2.50	0.5 – 0.8		

3.4.7. Attenuation of impact loads by fastening system

EN 13481-2 defines requirements for fastening system to be used for concrete sleepers. Fastening systems, with their associated rail pads, can be classified according to the reduction of strain to a reference case as follows:

- ✓ Low attenuation;
- ✓ Medium attenuation;
- ✓ High attenuation.

The rail pad reduces (attenuate) the load which is coming from the rail. Therefore we have to use impact attenuation factors which are applied to design loads. BS EN 13230-6 recommends reducing the attenuation values measured for the fastening system by 25 % in the normal case to allow for the service condition. The factor which is used to take into account the attenuation of the impact load for different attenuation is shown in Table 3.8.

Table 3.8: K_p values

Types of pads with their attenuations	K_p value
For pads with low attenuation (< 15 %)	1.0
For pads with medium attenuation (15 % to 30 %)	0.89
For pads with high attenuation (> 30 %)	0.78

3.4.8. Design of concrete sleeper according to BS EN 13230-6

3.4.8.1. Calculation of normal dynamic rail seat load P_k

The dynamic rail seat load, used to derive the basic characteristic bending moment, is calculated according to Equation (3.14) below.

$$P_k = \frac{A_{nom}}{2}(1 + k_p \times k_v) \times k_d \times k_r \qquad (3.14)$$

Where K_d, k_p and k_v are factors to take into account for different conditions as indicated in Table3.6, 3.8 and Figure 3.3 respectively. The values of k_r can be taken as 1.35.

3.4.8.2. Calculation of the characteristics bending moment

For the calculation of the characteristic bending moments, the uneven distribution of the ballast reaction under the sleeper and the elasticity of the sleeper are taken into account (BS EN 13230-6, 2014).

a) Bending moments for rail seat of sleepers

The bending moment at the rail seat is influenced by the ballast reaction, the width of the rail foot and the geometry of the sleeper. The positive bending moment $M_{k,r,pos}$ may be calculated from P_k using the beam on elastic foundation with a constant bedding modulus over the length 2 L_p. A load distribution in the sleeper according to Figure 3.4 and a constant ballast reaction over the length 2 L_p may be assumed. The uneven ballast reaction is taken into account by the factor $k_{i,r}$ as shown in Table 3.7.

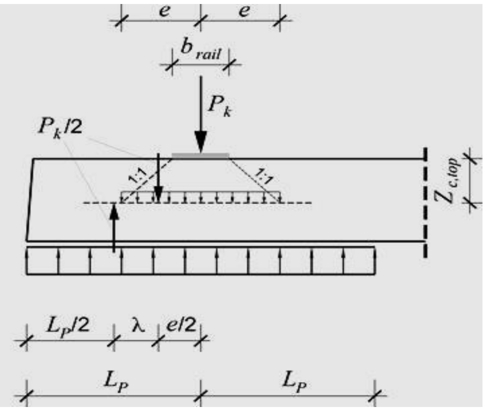


Figure 3.4: Design model for $M_{k,r,pos}$

Characteristic bending moment may be calculated as:

$$M_{k,r,pos} = k_{ir} \times \lambda \times \frac{P_k}{2} \qquad (3.15)$$

where,

λ is lever length of resulting internal forces

$$\lambda = \frac{L_p - e}{2} \qquad (3.16)$$

where,

b_{rail} is the width of the rail foot;

z_{ctop} is the distance to the axis of inertia from the top surface of the sleeper

$$e = \left(b_{rail} + 2z_{ctop}\right)/2$$

The length of the ballast pressure is equal to L_p :

$$L_p = \frac{L - c}{2} \qquad (3.17)$$

where,

c is the rail seat center spacing;

L is the sleeper length.

BS EN 13230-6 recommends the negative bending moment at the rail seat section to be 50% of $M_{k,r,pos}$ for sleeper length between 2.5m and 2.6m and minimum of 70% of $M_{k,r,pos}$ for shorter sleepers.

b) Bending moments for center part of sleepers

The characteristic value of the negative bending moment for sleepers with variable stiffness and different bottom width may is calculated as:

$$M_{k,c,neg} = k_{ic} \times P_k \times M_{c,neg,100} / 100 \qquad (3.18)$$

where,

$M_{c,neg,100}$ is the negative bending moment at the center of the sleeper.

The value of $M_{c,\ neg,\ 100}$ is dependent on the sleeper stiffness and different bottom width as shown in Figure 3.5.

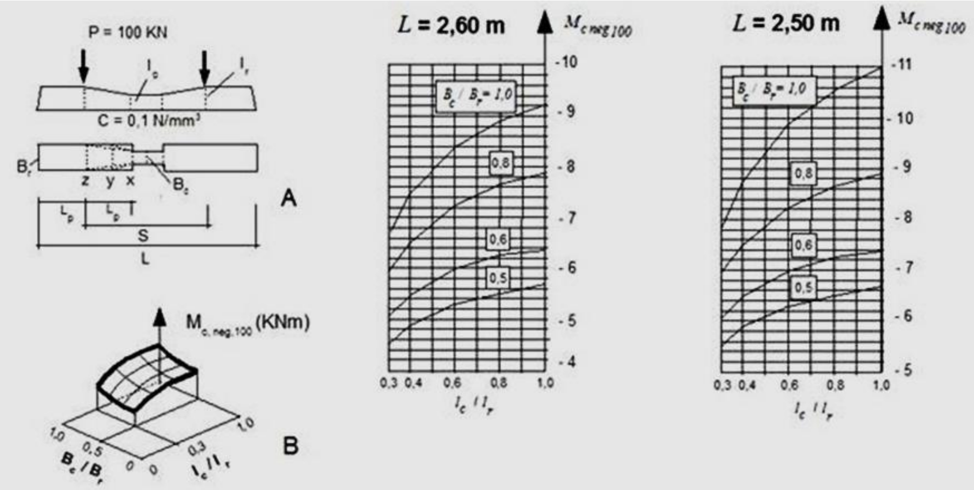


Figure 3.5: $M_{c,\ neg,\ 100}$ for standard gauge sleepers

For a trapezoidal bottom transition as indicated by z in Figure 3.5, Drawing A, the bending moment may be reduced by 10 %. For an intermediate transition as indicated by y in Figure 3.3, Drawing A, the bending moment may be reduced by 5 %.The characteristic positive bending moment for standard gauge sleepers with a length 2.20 m $\leq L \leq$ 2.60 m may be assumed as:

$$M_{k,c,pos} = 0.7 \times M_{k,c,neg} \tag{3.19}$$

3.5. German railway concrete sleepers

3.5.5. Material requirement

The material requirements of concrete sleepers used in Germany are based on the European standard. The lists of materials requirement used for the production of concrete sleepers are listed below.

a) Cement:- Portland cement type CEM 1 with minimum strength-grade class 42.5
b) Aggregate

c) Wire tendons

d) Concrete: - the minimum compressive strength is not less than 55MPa.

e) The water cement ratio shall not be less than 0.45.

3.5.6. Dimensions

RAIL.ONE (RAIL.ONE GmbH, 2004) delivers innovative track systems for railway transport in Germany and around the world, furthermore offers the production of concrete main-track and turnout sleepers. RAIL.ONE defines the requirements placed on the sleeper designs, specifies the necessary prestressing and strength of the concrete sleeper body, and adapts sleeper geometry to the conditions of the application environment: for example, sand drifts in desert regions. The company produces concrete sleepers for railways, urban transit and heavy-haul for both ballasted and ballastless tracks as shown in Table 3.9.

Table 3.9: Concrete sleepers used in Germany produced by Rail.one (RAIL.ONE GmbH, 2004)

Track line	Types of concrete sleepers	For ballasted track	For ballastless track
Railways	B 70, B 70-2.4, B 75, B 90, B 93, B 93.1, B 01, B 07, BBS 1, BBS-BÜ, B 320 and TURNOUT	✓	
	B 355.3 U54/60M, B 355.3 W54/60M-Fa, B 355.5 U54/60M, B 355.6 U GB60M, B 355.4 U54/60M, B 355.2 DFF54/60M, B 355.1 NL-U60M, B 355 P60-20MC, GWS 05, B 355 TS W60, B 355.3 TS/60M-BS, B 316 W54/60 and BBS 3 W54/60		✓
Urban transit	B 58, LIS 12 (1000), LIS 27 (1435), TBS 1000, TBS 1435, TBS 1450, TBS 1458, RTB 220/3S and SK40, TURNOUT	✓	
	ATD-GG1435 W Ri180, ATD-GG 1435 W49, TB/ZB 1435 SP, TB/ZB 1435 W and ZB 07		✓

Table 3.10 and Figure 3.7 below shows B 70 concrete sleepers dimension and 3D-viewsused for 25 tone axle load and 160km/hr line speed respectively.

Table 3.10: Dimension of B 70-2.4 concrete sleepers

Parameters	Unit
Permissible axle loads	25 t
Maximum speed	160 km/h
Concrete grade	C 50/60
Concrete volume	104 l
Weight (without fastenings)	260 kg
Length (L)	2400 mm
Width (W)	300 mm
Sleeper height (H)	234 mm
Height of centre of rail base (h_1)	214 mm
Height of sleeper centre (h_2)	175 mm
Support surface (total)	6237 cm^2
Standard application	Main-track sleeper

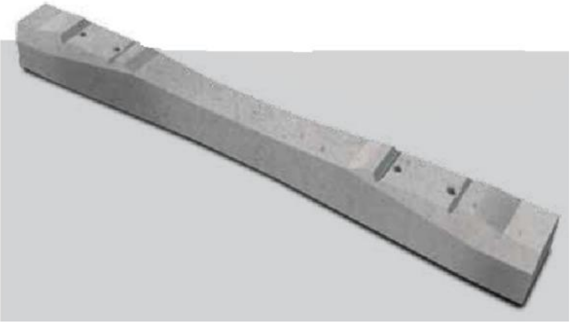


Figure 3. 6: 3D view of B 70-2.4 concrete sleeper

3.5.7. Load

As described in EN 13230-1 the track is subjected to repeated loads in three different directions, generally applied simultaneously:

a) Vertical loads depending on support conditions;
b) Transverse loads from guiding forces, transverse resistance, etc.;
c) Longitudinal loads from acceleration and braking, thermal stresses in continuous welded rail, etc.

The design load is calculated by applying a dynamic coefficient to the static wheel load. The dynamic coefficient takes into account the normal dynamic effects of wheel and track irregularities (EN 13230-1, 2009).

3.5.8. Load distribution

The assembled rail, fastening system and concrete sleepers and bearers on ballast or other support shall be considered as a beam on a continuous resilient support (EN 13230-1, 2009). The moment of inertia of the rail profile, the spacing of the concrete sleepers and the elasticity of the whole assembly on its support, have an influence on the longitudinal distribution of the vertical loads applied on the rail (EN 13230-1, 2009). As a result, the load applied on the concrete element is only a proportion of the design load.

3.5.9. Bending moment calculations

Determination of bending moment takes into account many data (EN 13230-1, 2009) such as:

- ✓ Static and dynamic wheel loads from the rolling stock
- ✓ Design and maintenance of the track including longitudinal distribution of wheel loads and uneven bearing of sleepers

- ✓ Climatic conditions
- ✓ Long term magnitude of the prestressing force and the long term strength or behaviour of the concrete

Many ways can be used for the determination of the bending moment used in EN 13230:

- ✓ Experimental with dynamic tests;
- ✓ Evaluation of performance in real track conditions;
- ✓ Theoretical calculation.

For the theoretical calculation of design bending moments, the European standard of concrete sleepers or CEN members uses UIC Report 713 R "Design of mono-block concrete sleepers", 1st edition, November 2004, which gives data for the calculation of bending moments under rail section and at center section for 1435 mm gauge sleepers (EN 13230-1, 2009).The bending moment at different location of concrete sleepers is discussed briefly below.

3.5.9.1. Positive bending moment at the rail seat (M_{dr})

There are three positive bending moment at the rails seat that are defined in EN 13230-1. These are:

- ✓ Wheel load positive bending moment
- ✓ Exceptional loading bending moment
- ✓ Ultimate bending moment

According to (EN 13230-1, 2009) exceptional loading bending moment due to exceptional and random impact loads and is calculated by multiplying the design bending moment (M_{dr}) by coefficient (k_1). Any crack produced by this bending moment shall close upon removal of the bending moment. Exceptional bending moments occur only a few times in the lifetime of a concrete sleeper and bearer. It is the responsibility of the purchaser to determine the coefficient (k1) to be applied to the design bending moment (EN 13230-1, 2009).

The third stage of the bending moment is the ultimate bending moment due to accidental impacts, calculated by multiplying the design bending moment (M_{dr}) by coefficient (k_2) (EN 13230-1, 2009). The purchaser shall state the coefficient (k_2) to be applied to the design bending moment.

3.5.9.2. Negative bending moment at the rail seat (M_{drn})

As it is explained in EN 13230-1 negative bending moments under the rail seat can arise from vertical movement of the track, harmonic motion from rail corrugation and curving forces of the sleeper under dynamic loading and handling during track works (EN 13230-1, 2009).

3.5.9.3. Bending moment at the center

Both the positive (M_{dc}) and negative (M_{dcn}) bending moment at the center part is determined by the purchaser (EN 13230-1, 2009).

3.6. China railway concrete sleepers

3.6.5. Type and dimensions of concrete sleepers

According to Code for Design of Railway Track (TB10082-2005) the Chinese prestressed concrete sleepers can be divided into four types:

- ✓ Type I prestressed concrete sleeper
- ✓ Type II prestressed concrete sleeper
- ✓ New type II prestressed concrete sleeper and
- ✓ Type III prestressed concrete sleeper

Detail dimensions of the above types concrete sleepers is discussed in Table 3.11 below.

Table 3.11: Geometric properties of prestressed concrete sleepers used in china

Sleeper type	No of Tendon	Concrete Grade	Section height (mm)		Cross-section width (cm)			Bottom area (cm^2)	Weight (kg)	Length (cm)
			Under rail	Middle	End	Under rail	Middle			
I	36ϕ3.0	C48	20.2	16.5	29.45	27.5	25	6588	251	250
II	44ϕ3.0	C58	20.2	16.5	29.45	27.5	25	6588	251	250
II New	16ϕ5.0	C58	20.5	17.5	18.50	16.9	19	6700	273	250
	10ϕ6.3				31.00	28.0	25			
III	10ϕ7.0	C60	23.0	18.5		30.0	28.0	7720	320	260

3.6.6. Design bending moment

3.6.6.1. Maximum positive moment under the rail

The maximum positive moment under the rail seat is calculated taking into account that the sleeper is support by the effective length only. The center part of the sleeper is taken to be unsupported as shown in Figure 3.7. The value of the maximum rail seat load is calculated by using Equation (3.20).

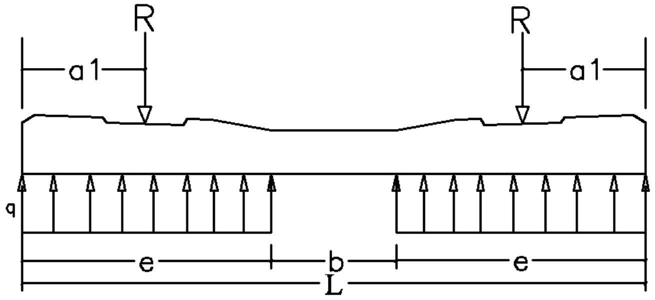


Figure 3.7: Ballast support for maximum positive bending moment under the rail recommended by TB

$$M_g = K_s\left[\frac{a_1^2}{2e} - \frac{b'}{8}\right]R_d \leq \left[M_g\right] (3.20)$$

where,

M_g = rail seat moment (=0.147R_d),

$[M_g]$ = Maximum positive rail seat moment,

R_d = the design rail seat load,

a_1 = length from edge of sleeper to center of rail seat,

b' = pad width (=0.15 recommended for new type II),

e = effective support length (=0.95m recommended value by code of practice),

b_1 = unsupported length of sleeper,

q = ballast pressure (=1.053R_d)

$$R_d = \frac{Q \times DF \times j}{100} \tag{3.21}$$

where,

q_s = design static wheel load

DF = Distribution factor in percent (47.92% for sleeper spacing of 60cm)

j = factor for dynamic load (j>2.5)

3.6.6.2. Maximum negative moment at the middle

The maximum negative moment at the rail seat can be calculated taking the ballast support to be uniform along the sleeper except the center part of the sleepers which support 75% of ballast pressure as shown in Figure 3.8.

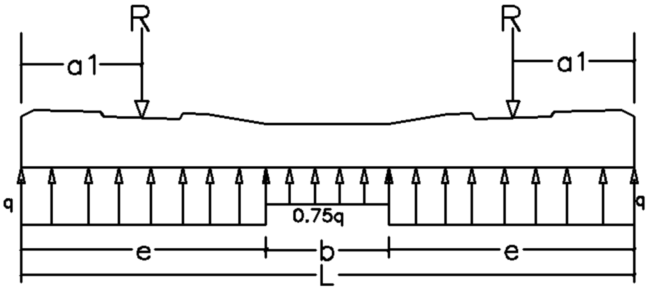


Figure 3.8: Ballast support for maximum negative bending moment at the middle of the sleeper recommended by TB

The maximum negative bending moment at the middle of the sleeper can be calculated using Equation 3.22.

$$M_c = -K_s \frac{3l^2 + 4e^2 - 8a_1e - 12a_1l}{4(3l + 2e)} R_d \leq [M_c] \tag{3.22}$$

where,

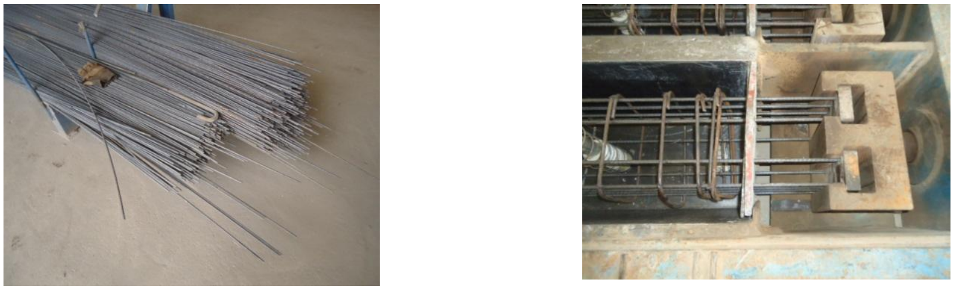
M_c = center moment from loading effect (=0.13R_d),

[M_c] = Maximum negative moment at the middle.

Q = ballast pressure (=0.851Rd)

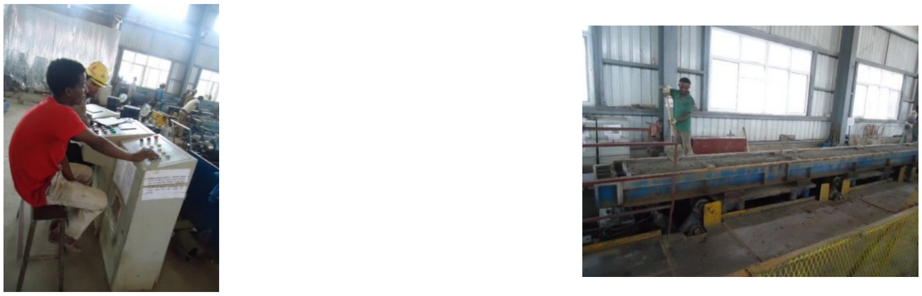
3.6.7. The Chinese concrete sleepers production in Ethiopia

Currently Ethiopia is constructing the railway by contractual agreement with Chinese contractors. As it is explained in problem of the statement, the design and manufacturing of concrete sleepers is done using Chinese standard. Preliminary study has not been conducted in order to verify the suitability of the sleeper in terms of long-term flexural performance, durability safety etc. (personal communication) for Ethiopian condition. The concrete sleepers used for national railway lines are Type II concrete sleepers and the detail dimension is shown in Table 3.11 above. The manufacturing of concrete sleepers is done in Welenchiti and Diredewa towns. The production stages of concrete sleepers at Welenchiti town are shown in Figure 3.9.



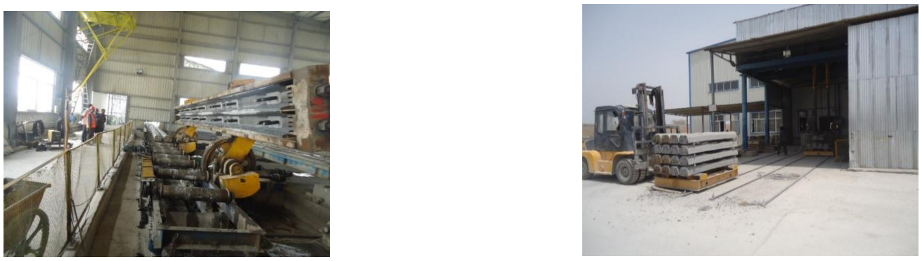
a) Bonding of tendons to form strands

b) Arrangement of tendons to prestressed



c) Application of prestressing force

d) Concrete casting



e) Separating sleepers

f) Sleeper taken to steam curing and storage

Figure3.9: Concrete Sleeper Production in process Ethiopia

CHAPTER FOUR

MODELING OF RAILWAY PRESTRESSED CONCRETE SLEEPER

4. Static Modeling of Railway Concrete Sleeper

Static modeling of railway prestressed concrete sleepers is performed using different modeling approaches (Konstantinos, 2012). These are:

- ✓ Discrete elastic support model
- ✓ Continuous rail support model
- ✓ Beam on elastic foundation model

In this thesis static modeling is performed using discrete elastic support model. The sleepers are modeled as 3D-solid element (Solid65) using ANSYS software while the reinforcing (link8) tendons are modeled as an embedded truss element. The bond slippage between the tendons and concrete is ignored since only global analysis is required (Shan Li, 2012). Static load on all sleepers is based on Ethiopian axle load capacity i.e. 25tone. The concrete sleepers used for the model are standard gauge sleepers.

4.1. Dynamic modeling of concrete sleepers

Dynamic modeling is based on discrete rail support model in which the rail (a beam) is placed on a spring and a damper in parallel (Konstantinos, 2012). According to this model:

- ✓ Rail is modeled as a beam
- ✓ The rail pads are modeled by spring-damper systems,
- ✓ The sleepers is modeled as rigid masses, and
- ✓ The ballast as an elastic foundation is modeled by spring-damper systems.

The concrete sleepers are modeled as 3-D solid element and the tendons are modeled as truss elements. The support interaction between the sleeper and the ballast is modeled as spring-damper system i.e. COMBIN 14 elements in ANSYS which allows the sleepers to move up and down. The sub ballast is modeled as a solid element with fixed support. The non-linear material behaviors of concrete and possible cracking conditions are not included. To simplify the analysis procedure a sine curve dynamic load have been introduced, when assuming one single dynamic loading wave passes one single sleeper with the speed of 130 km/h, and with no irregularities of the rail or the wheel profile (Shan Li, 2012).The time history of this dynamic rail seat load is illustrated as Figure 4.1.

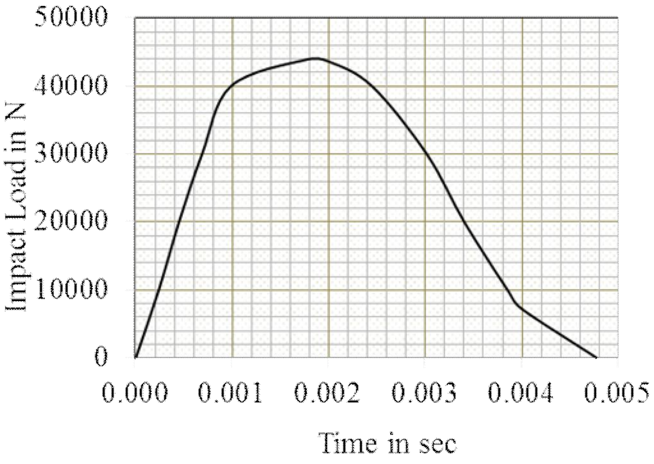
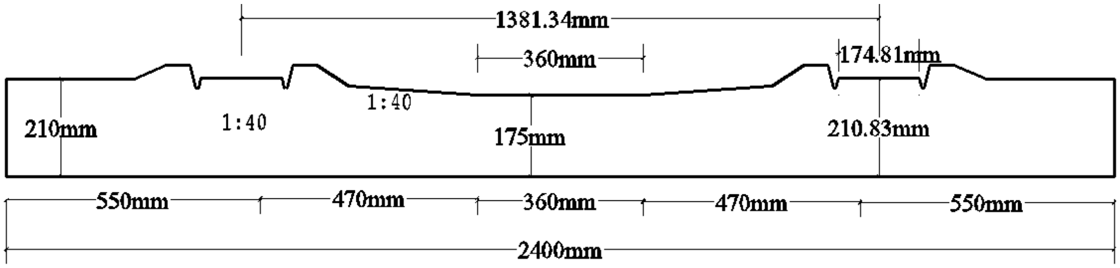


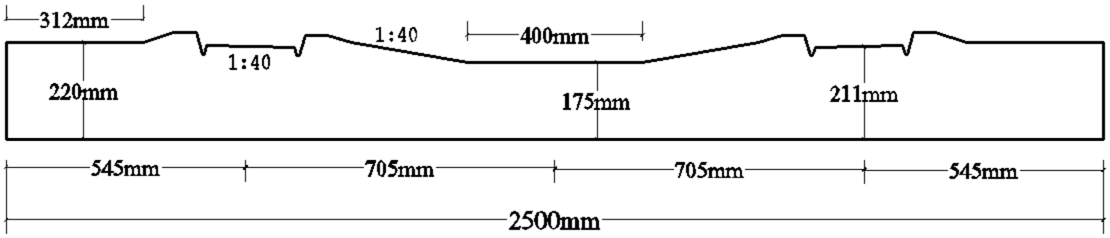
Figure 4.1: Time history of dynamic rail seat load

4.2. Modeling of concrete sleepers for five (5) countries

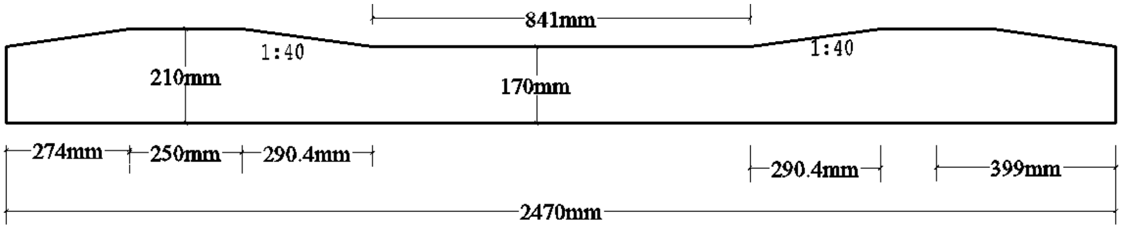
Modeling and analyzing the concrete sleepers under static and dynamic load for four countries is the main concern of this thesis. During analysis all concrete sleepers (standard gauge prestressed concrete sleepers) are subjected to the same axle load (25 ton and structural design parameters, i.e. the case of Ethiopian railway track design). In this thesis discrete support model is adopted, since it describes the real situation of track (Konstantinos, 2012). The material properties, the dimensions, number of tendons used and other geometric and structural design parameters are based on the code provisions of respective countries. Modeling and analysis of the sleepers is done using finite element analysis software ANSYS. The response (rail seat positive and negative moment, sleeper center positive and negative bending moment and ballast supports) for static analysis of the concrete sleepers are compared and finally evaluated with AREMA standards for prestressed concrete sleeper. In Figure 4.2 (a-d), a 2D view and geometric characteristics of four concrete sleepers used for modeling are described.



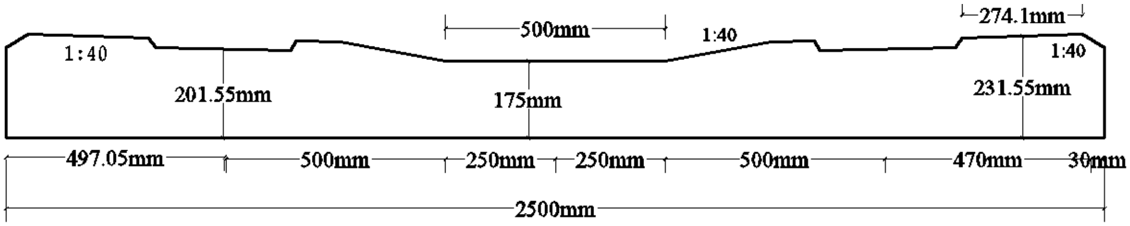
a) Standard gauge prestressed concrete sleeper used in German



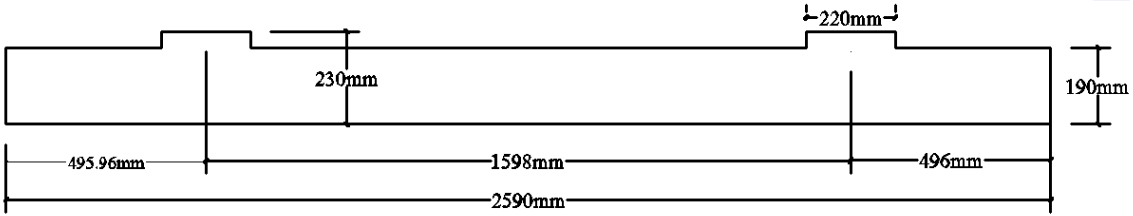
b) Standard gauge prestressed concrete sleeper used in British



c) Satandard gauge prestressed concrete sleeper used in Australia



d) Standard gauge prestressed concrete sleeper used in China



e) AREMA standard sleeper

Figure 4.2: 2-D view of prestressed concrete sleepers of four countries

The dimension of prestressed concrete sleepers at the rail seat and at the middle of sleeper, properties of concrete and properties of tendons are described in Table 4.1, Table 4.2 and Table 4.3 respectively.

Table 4.1: Geometric parameters of prestressed concrete sleepers (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)

Item No	Sleepers	Sleeper length (mm)	Rail seat			Center		
			Bottom width (mm)	Top width (mm)	Height	Bottom Width (mm)	Top Width (mm)	Height (mm)
1	German sleepers	2400	300	160	224	300	160	175
2	British Sleepers	2500	250	170	211	250	170	175
3	Australian	2470	250	210	170	250	220	170
4	China Sleepers	2500	280	190	202	280	190	175
5	AREMA Sleeper	2590	260	180	190	260	180	190

Table 4.2: Properties of concrete used for modeling (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)

Item No	Properties of concrete	Australia	German	British	China	AREMA
1	Density (ρ_c) in kg/m^3	2750	2400	2500	2500	2400
2	Young's modulus (E_c) in	37.45	39.00	39.00	35.00	37.014
3	Poisson's ratio (ν_c)	0.20	0.20	0.20	0.20	0.2

4.2.1. Design rail seat load calculation

As it is explained in state of art in chapter three there are different methods of calculating the design rail seat load depending on code provisions of respective countries.

i) According to Australian standard

$$R = \frac{j \times Q \times DF}{100}$$ DF= 47.92%, j = 2.5 and Q = 125kN

$$= \frac{2.5 \times 47.92 \times 125\text{kN}}{100} = 149.75\text{kN}$$

ii) According to china

$$R_d = \frac{q_s \times DF \times j}{100}$$ qs =125kN, DF=47.92% and j=2.5

$$R = \frac{125 \times 47.92 \times 2.5}{100} = 149.75kN$$

iii) According to German and British

$$P_k = \frac{A_{nom}}{2}(1 + k_p \times k_v) \times k_d \times k_r$$

For pads with medium attenuation (15 % to 30 %): k_p = 0.89, k_d=0.40for 50kg rail and $k_r = 1.35$

$$k_v = 0.25 + \frac{V - 60}{280} = 0.25 + \frac{120 - 60}{280} = 0.464$$

$$P_k = \frac{250000}{2}(1 + 0.89 \times 0.464) \times 0.4 \times 1.35 = 95.374kN$$

Table 4.3: Properties of reinforcing tendons used for the modeling (Committee CE-002, 2003, BS EN 13230-1, 2014, EN 13230-1, 2009 and TB10082, 2005)

Item	Properties of wire	Australia	German	British	China	AREMA
1	Density (ρ_s) in kg/m^3	7850	7850	7850	7500	
2	Young's modulus (E_s) in GPa	190	195	195	193	190
3	Poisson's ratio (ν_s)	0.30	0.30	0.30	0.3	0.3
4	Prestressing force in kN	250	315	315	384	468.27
5	Design rail seat load (kN)	149.75	95.37	95.37	149.75	124.2
5	Number strands	12ϕ8mm	4ϕ8m	4ϕ8m	10ϕ6.	10 ϕ9.53

4.3. Finite element model

Prestressed concrete sleeper is modeled as 3D-solid element while the reinforcing tendons are modeled as a 3D-link element. The solid and link elements can be best represented by SOLID65 AND LINK8 elements available in ANSYS element library. The reinforcing tendons are embedded in the concrete and the bond slippage between the two elements is ignored. The detail about the two elements is explained below. The analysis is based on the ballast pressure distribution that each countries code recommend and the Chinese ballast pressure distribution which accounts the non-uniform ballast pressure under sleeper.

4.4. Elements used for finite element

4.4.1. SOLID65 Element

SOLID65 element in ANSYS is used for the 3-D modeling of solids with or without reinforcing bars. The solid is capable of cracking in tension and crushing in compression. The element can be used to model solid concrete elements, reinforced composites (such as fiberglass) and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep (ANSYS help manual). The geometry of the element is shown in Figure 4.3 below.

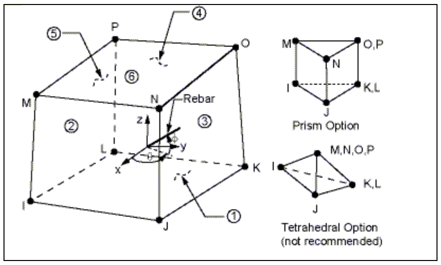


Figure 4.3: Solid65 element geometry

4.4.2. LINK8 Element

LINK8 in ANSYS used to model trusses, sagging cables, links, springs, etc. The element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included (ANSYS help manual). The geometry of the element is shown in Figure 4.4 below.

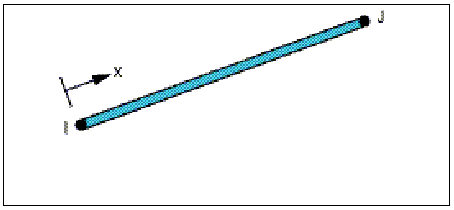


Figure 4.4: Link8 element geometry

4.5. Flexural performance requirements for prestressed mono-block designs according to AREMA standard for concrete sleeper

4.5.1. Ballast pressure

AREMA recommends the average ballast pressure under the sleeper to be

$$\text{Average ballast pressure} = \frac{(2P)\left[1+\frac{IF}{100}\right]\left(\frac{DF}{100}\right)}{A} \tag{4.1}$$

where,

P = Wheel load in (kN) taken as 125kN

IF = Impact factor in percent taken as 200%

DF = Distribution factor in percent (47.92% for sleeper spacing of 60cm)

A = Bearing area of cross ties in square millimeters and is 2/3 footprint of the tie

$$\text{Average ballast pressure} = \frac{(2\times 125)\left[1+\frac{200}{100}\right]\left(\frac{47.92}{100}\right)}{A} = \frac{359.36}{A}\,\text{kPa}$$

The average ballast pressure for each concrete sleeper is calculated using Equation (4.1) above as shown in Table 4.4.

Table 4.4: Average ballast pressure

Concrete sleepers	Bottom area mm^2	Average ballast pressure kPa
German standard gauge prestressed concrete sleeper	720000	499.17
British standard gauge prestressed concrete sleeper	625000	575.04
Australian standard gauge prestressed concrete sleeper	617500	582.02
China standard gauge prestressed concrete sleeper	700000	513.43
AREMA standard gauge prestressed concrete sleeper	448933.333	586.00

The recommended ballast pressure should not exceed 0.586 MPa for high-quality, abrasion resistant.

4.5.2. Bending moments

Considering the influence of speed and annual tonnage on the tie design, the factored design flexural capacity may be determined from:

$$M = B \times V \times T \qquad (4.2)$$

where,

M = the factored design positive bending moment at the center of the rail seat

B = the bending moment in inch kips (kN-m) for a particular tie length and spacing

V = is the speed factor obtained from figure

T = the tonnage factor

The bending moment B, the speed factor V and tonnage factor T are determined according to AREMA standard. The factored design positive bending moment for rail seat section is calculated with the annual tonnage of 22 mill gross tons per annum and speed of 120 km/hr according to Ethiopian national rail way specification. Negative factored design bending moment at the rail seat and the positive and negative factored design bending moment at sleeper center is obtained from positive bending moment M at rail seat as shown in Table 4.5.

Table 4.5: Bending moment calculation (AREMA, 2010)

Tie Length	Rail seat Negative	Center Negative	Center Positive
7'-9" (2.36 m)	0.72M	1.13M	0.61M
8'-0" (2.44m)	0.64M	0.92M	0.56M
8'-6" (2.59m)	0.53M	0.67M	0.47M
9'-0" (2.74m)	0.46M	0.57M	0.40M

Factored design positive bending moment at the rail seat is calculated for each sleeper from Equation (4.2).

$M = B \times V \times T$

$= 26.288 \times 0.751 \times 0.973 = 21.720$kN-m -----------------for L=2.40m

$= 29.464 \times 0.751 \times 0.973 = 24.345$kN-m ---------------- for L=2.50m

$= 28.312 \times 0.751 \times 0.973 = 23.393$kN-m ---------------- for L=2.47m

$= 29.464 \times 0.751 \times 0.973 = 24.345$kN-m ---------------- for L=2.50m

The factored positive bending and negative bending moments at rail seat and at the center shown in Table 4.6 below is interpolated from Table 4.5 according to sleeper's length.

Table 4.6: Factored design positive and negative bending moment at the rail seat and at sleeper center

Sleepers	Sleeper length (m)	Rail Seat Positive (kN-m)	Rail Seat Negative (kN-m)	Center Negative (kN-m)	Center Positive (kN-m)
German sleeper	2.40	19.209	13.062	19.689	11.237
British sleeper	2.50	21.530	13.306	18.731	11.669
Australian sleeper	2.47	20.688	12.330	16.964	10.841
China sleeper	2.50	21.530	12.832	17.655	11.282
AREMA sleeper	2.59	24.168	12.809	16.193	11.359

4.6. Rail seat and sleeper center positive and negative bending moment support location

The support location for positive and negative bending moment is at one third (1/3) of the distance from one end of sleeper to rail seat center and for center bending moment (positive and negative) the support is at 762mm from the center of sleeper (AREMA, 2010).The location of support is shown in Appendix B

4.7. Validation of finite element result

Finite element validation is done by comparing the result (finite element result) with AREMA recommendations. Table 4.7 shows comparison of the two results and percentage error both at rail seat and sleeper center for both positive and negative bending moments.

Table 4.7: Comparison of the FE result with the AREMA recommendations for both negative and positive values of bending moment at rail seat and sleeper center

Sleepers	Finite element bending moment result (in kN-m)				AREMA bending moment values (in kN-m)			
	Rail seat		Sleeper center		Rail seat		Sleeper center	
	M(+)	M(-)	M(+)	M(-)	M(+)	M(-)	M(+)	M(-)
German concrete sleeper	9.331	22.327	15.253	34.573	19.209	13.062	11.237	19.689
British concrete sleeper	10.197	13.637	17.734	26.162	21.530	13.306	11.669	18.731
Australian concrete sleeper	4.966	7.883	14.812	20.829	20.688	12.330	10.841	16.964
China concrete sleeper	6.633	9.833	15.469	23.688	21.530	12.832	11.282	17.655
AREMA sleeper	15.79	15.18	27.21	37.39	24.168	12.809	16.193	11.359

ANSYS as finite element software is used by researchers in order to model prestressed concrete sleepers for different cases. Among the researchers that use the package to model railway prestressed concrete sleepers include:

1. Sakdirat K aewunruen and Alexander Remennikov

They have used ANSYS FE software for modeling under the following topics

- ⊕ Rotational capacity of railway prestressed concrete sleeper under static hogging moment.
- ⊕ Resistance of railway concrete sleepers to impact loading.
- ⊕ Low-velocity impact analysis of railway prestressed concrete sleepers.
- ⊕ Experimental and Numerical Studies of Railway Prestressed Concrete Sleepers Under Static and Impact Loads.

2. J. Bian, Y.T. Gu and M. Murray
   - ⊕ They used the software to study the numerical Impact Forces on Railway Sleepers under Wheel Flat.
3. Sakdirat Kaewunruen
   - ⊕ The software was used to evaluating dynamic behaviour of prestressed concrete sleepers subjected to severe impact loading

As it is shown in Table 4.7 the rail seat results for both positive and negative bending moments are less than the AREMA values which are acceptable. For results of bending moments at sleepers there is a difference in bending moment results i.e. the FE results have greater values than AREMA results. AREMA results are results which are obtained from experimental results and they are not one time result whereas the FE results are results which are obtained from iterations which involves different assumptions which may not represent the actual condition. The author takes the difference in the moment result at sleeper center as FE errors due to assumptions which may exist in the software.

CHAPTER FIVE

FINITE ELEMENT RESULTS AND DISCUSION

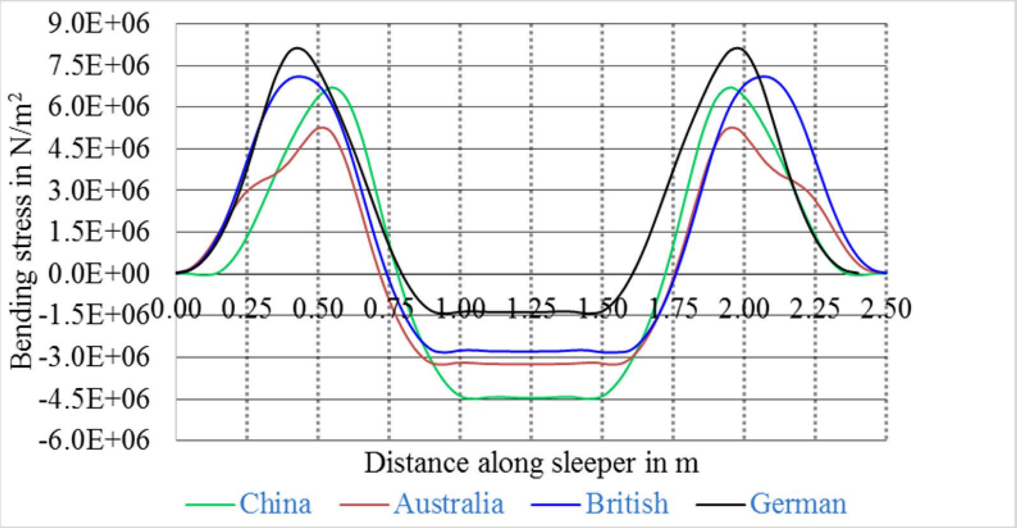
5. Discussion

From Figure 5.1 to 5.4 shows the values of stress on concrete sleeper due to ballast pressure recommended by each countries code and the Chinese ballast pressure distribution which will creates maximum bending moment at rail seat and sleeper center. The discussion of the result is based on the stress values at two points i.e. at sleeper rail seat and center. For each pressure distribution shown in Appendix B the effect at rail seat and sleeper center will be discussed.

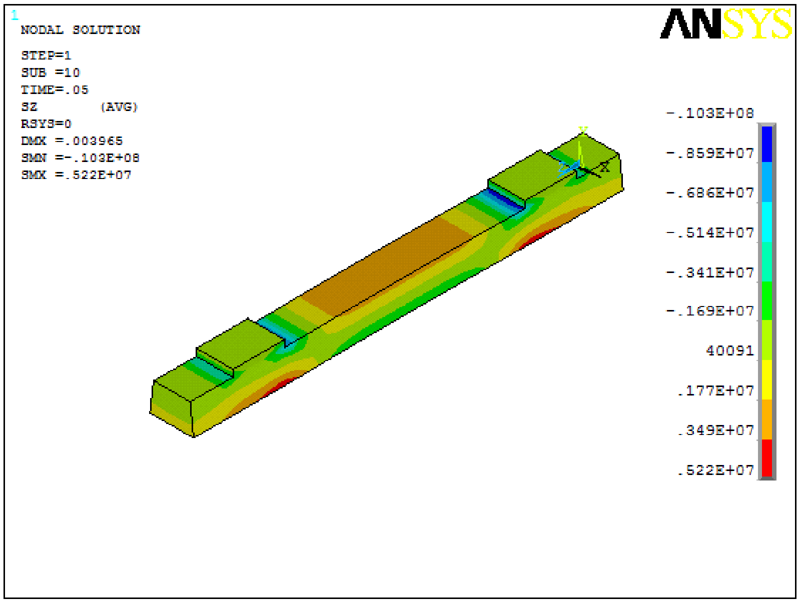
5.1. Stress results obtained according to ballast pressure distribution recommended by Chinese code of standard

5.1.1. Stress result which produce maximum bending moment at rail seat

From Figure 5.1 it is clearly shown that the maximum stress values occur at different location which is due to difference in sleeper length and location of rail seat area. The stress at rail seat of British and German concrete sleepers i.e. up to 300mm sleeper length is similar while the Australian and Chinese concrete sleeper's shows stress which is less. A maximum and a minimum stress value of about 8.04MPa and 5.22MPa have been observed at rail seat for German and Australian sleeper respectively. At sleepers center the German sleeper shows small values of stress whereas the Chinese sleepers has maximum negative stress of about 4.49MPa. At both rail seat and sleeper center the stress values of British sleepers has a medium response as it is observed from Figure 5.1.



a) Bending stress versus distance along sleeper

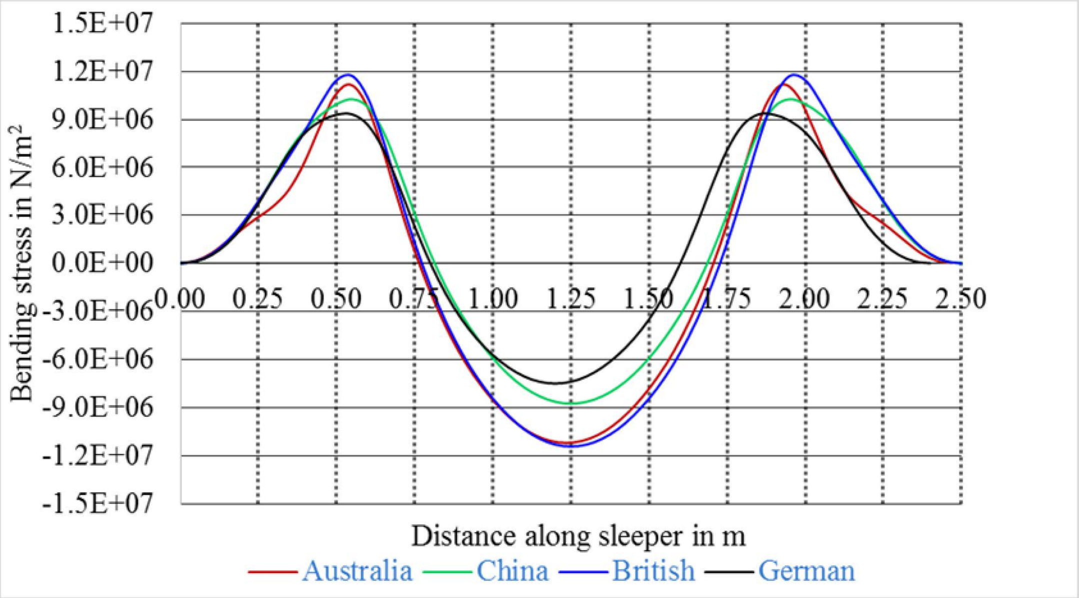


b) FE contour plot for bending stress

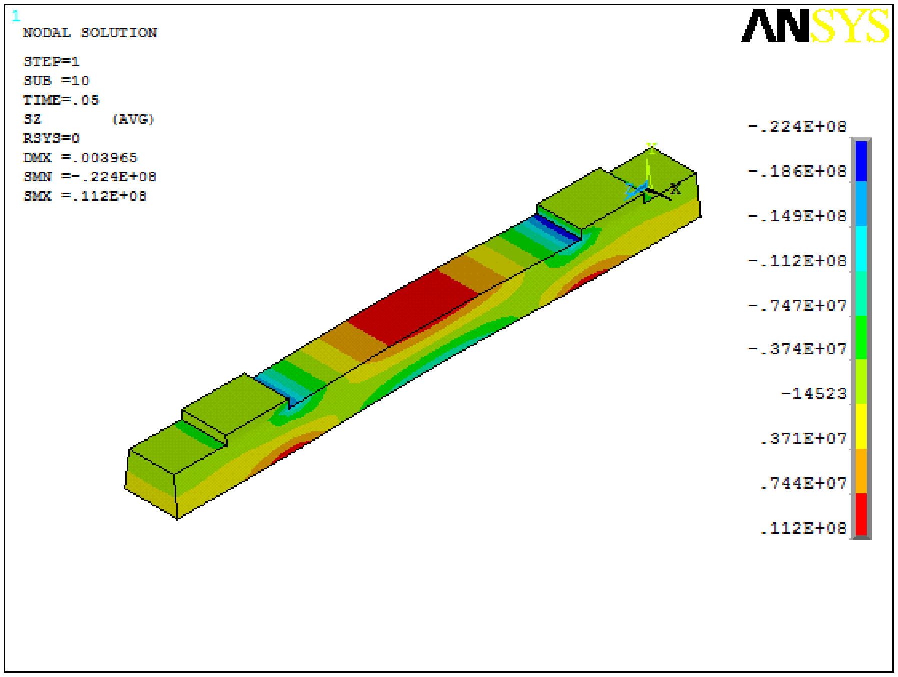
Figure 5.1: Bending stress due to positive rail seat load

5.1.2. Stress result which produce maximum bending moment at sleeper center

The German sleeper shows a maximum stress (9.31MPa) at rail seat and sleeper center (7.47MPa) which is less than the rest of concrete sleepers. A similar stress values at sleeper center has been observed for Australian and British sleepers whereas the Chinese sleeper has a medium stress results at both rail seat and sleeper center.



a) Bending stress versus distance along sleeper



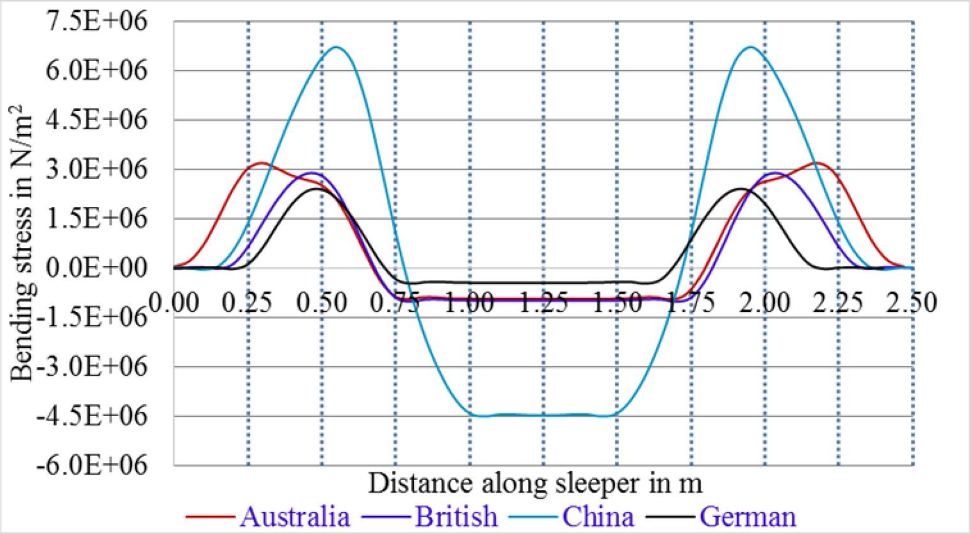
b) FE contour plot for bending stress

Figure 5.2: Bending stress due to sleeper center positive load

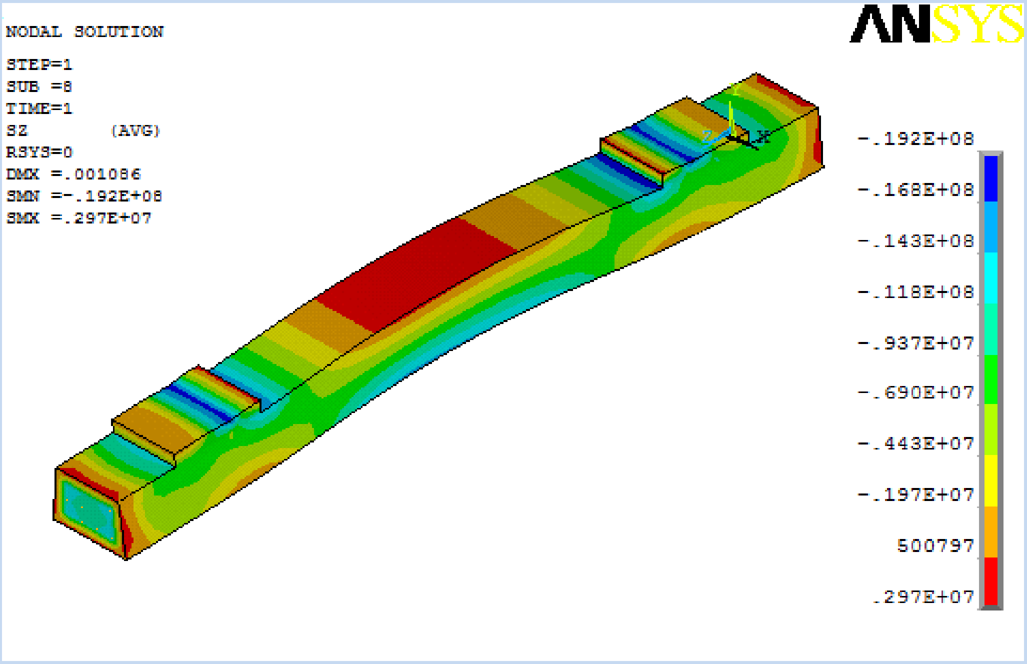
5.2. Static results according to ballast pressures recommended by each countries code

5.2.1. Stress result which produce maximum bending moment at rail seat

Figure 5.3 shows the stress values which produce maximum bending moment at rail seat according to ballast pressure distribution recommended by each countries standard. This ballast pressure distribution has been considered due to the fact that the actual contact between sleeper and ballast during operation is not uniform. From the analysis result it has been observed that there is a large value of stress at rail seat and sleeper center for Chinese sleeper whereas the German sleeper shows small value of stress at both locations. The maximum bending stress value at rail seat of Chinese sleepers (6.71MPa) is about 52, 57 and 64% greater than the stress values of Australian, British and German concrete sleepers whereas at sleeper center it is about 79, 78 and 90% greater respectively as shown in Figure 5.3.



a) Bending stress versus distance along sleepers

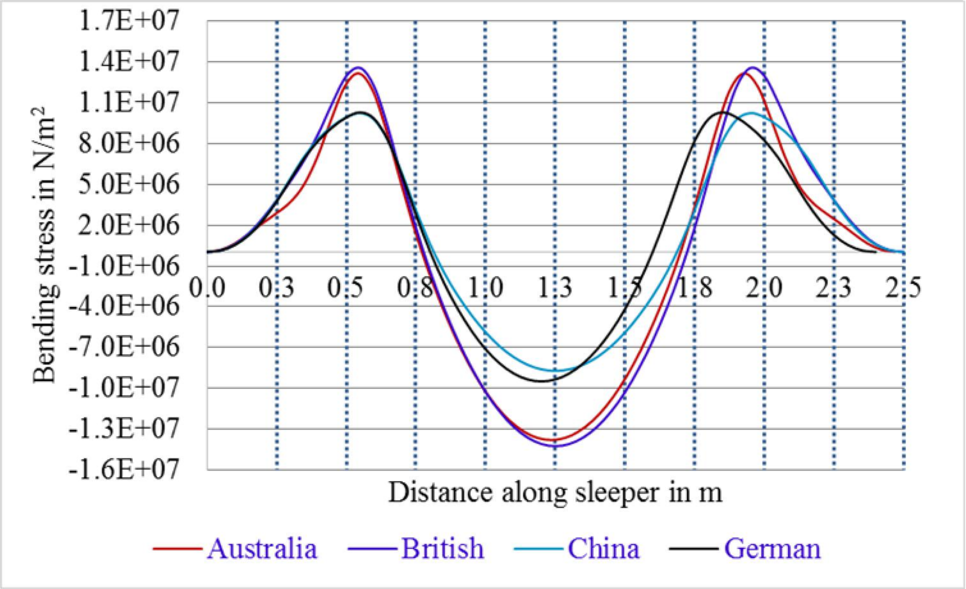


b) FE contour plot for bending stress

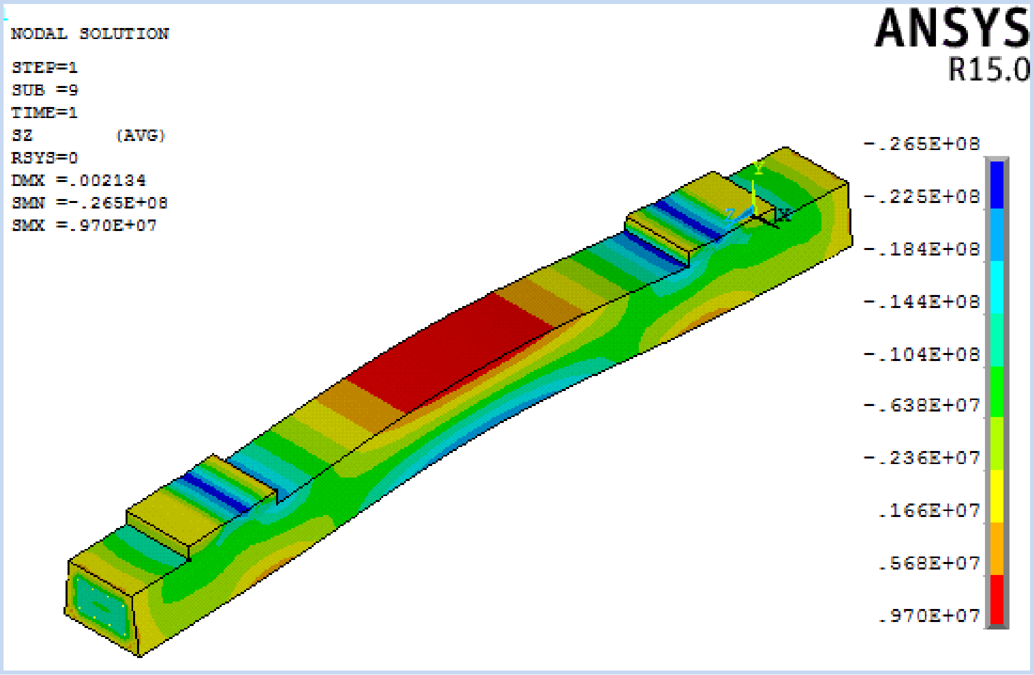
Figure 5.3: Bending stress due to positive rail seat load

5.2.2. Stress result which produce maximum bending moment at sleeper center

In this case a similar stress values of has been obtained from FE analysis for Australian and British concrete sleepers. The German and Chinese sleepers have a maximum rail seat stress value of about 1.03MPa which is equal 9.49 and 8.71MPa at sleeper centers. Form the result it has been observed that the Chinese cross-section shows a good result at both locations when compared with other concrete sleepers as it is shown in Figure 5.4.



a) Bending stress versus distance along sleepers

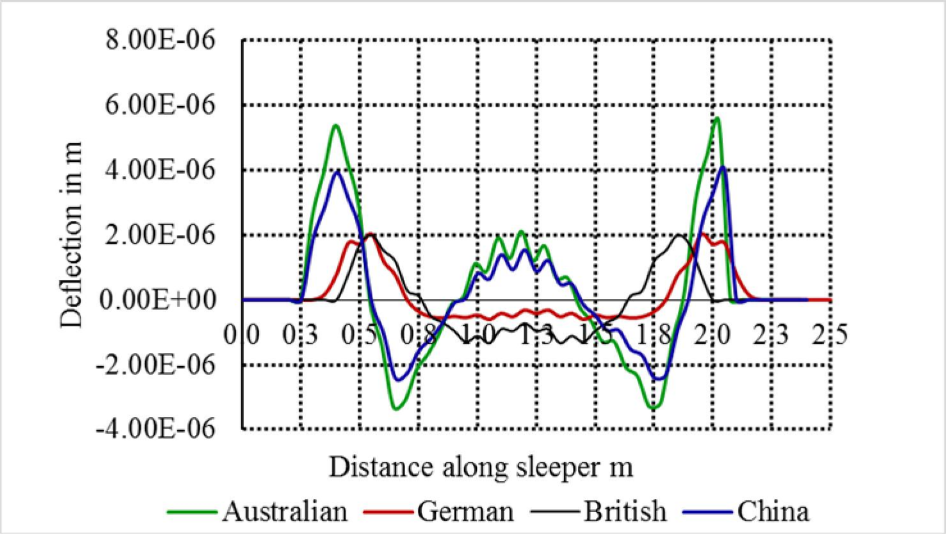


c) FE contour plot for bending stress

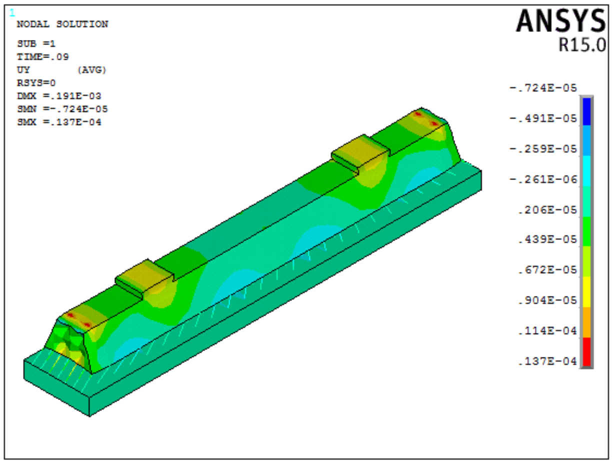
Figure 5.4: Bending stress due to negative sleeper center load

5.2.3. Dynamic results

Dynamic analysis has been conducted using an impact load which is expected to occur during operation of concrete sleeper. In all sleepers a dynamic load of the same magnitude shown in Figure 4.1 has been applied. Figure 5.5 shows the deflection due to dynamic load applied to concrete sleepers. From the result, the Australian and China concrete sleeper shows a large value of deflection at rail seat and sleeper center due to an impact load while German and British concrete sleepers shows small value of deflection both at rail seat and sleeper center. From the entire, the German concrete sleeper shows a good response for the dynamic load.



b) Deflection curve along sleeper due to dynamic load



c) Contour plot for deflection

Figure 5.5: Deflection of concrete sleepers due to dynamic load

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6. Conclusion

In this thesis assessment of different countries prestressed concrete sleepers and numerical modeling have been conducted. During assessment it has been observed that each countries have their own code of standard for the design and construction of railway prestressed concrete sleeper. The types of prestressed concrete sleeper can be divided into narrow gauge, standard gauge and broad gauge concrete sleepers. Some countries like Australian categories sleepers as heavy duty and medium duty prestressed concrete sleepers based on axle load capacity whereas Chinese categories as types I, II, type II new and type III prestressed concrete sleeper. From assessment it is observed that the classification of concrete sleepers depends on the axle load capacity. During service life, the sleepers are subjected to different types of loading such as static, dynamic, lateral, accidental loads and their design shall consider these loads. The longitudinal load distribution in Australian standard is based on the spacing between sleepers while for British standard, elastic beam on resilient support is used and the influence of all elastic track components is taken in to account. Even though codes of standard recommend uniform ballast support under sleepers, there is no predefined fact that shows the distribution of ballast support (reaction) under sleeper. Therefore an experimental and field investigation has to be conducted in order to determine the exact ballast reaction under sleeper.

Numerical analysis has been conducted using finite element software ANSYS to compare four countries prestressed concrete sleepers. The sleepers are compared taking the Ethiopian railway structural design parameters as a common. FE result was validated using AREMA standard and it is observed that the FE result shows that rail seat values are within AREMA values while sleeper center values had results greater than AREMA values and these difference are taken as errors due to different assumptions which may exist in the software.

The second FE analysis has been conducted using ballast pressure distributions recommended by code of standards. The ballast pressure distribution under sleeper for each country is shown in Appendix B. From analysis result it has been observed that Chinese concrete sleeper at rail seat and sleeper center shows a large stress value for stress values which produce maximum bending moment at rail seat and sleeper center when compared to other concrete sleepers. Again the German concrete sleeper shows small stress value of about

2.39MPa at rail seat and 0.461MPa at sleeper for stress which produce maximum bending moment at rail seat whereas British concrete sleeper shows small stress value of about 1.44MPa at rail seat for stress which produce a maximum bending moment at sleeper center.

The third FE analysis is based on ballast pressure distribution recommended by Chinese standard. From the result it was observed that the German concrete sleeper shows a maximum stress of 8.04MPa at rail seat and a minimum stress of 1.42MPa at sleeper center for stress which produce a maximum bending at rail seat. The Australian concrete sleeper has small stress at rail seat while the Chinese concrete sleeper shows a large stress result when compared with other concrete sleepers. For stress which produce a maximum bending moment at sleeper center the response of German concrete sleeper for external load is high and stress result of 9.31MPa at rail seat and 7.46MPa at sleeper center has been observed.

From the analysis result we can conclude the following points:

i. According to ballast pressure distribution recommended by each codes
   - ✓ The internal bending resistance of German concrete sleepers at rail seat and sleeper center is high for stress which produce maximum bending moment at rail seat and sleeper center respectively.
   - ✓ The cross-section resistance of British concrete sleeper at sleeper center is high for stress which produce maximum bending moment at sleeper center.
   - ✓ For maximum negative rail seat bending moment of German concrete sleeper cross-section shows a good result when compared to others.

ii. According to ballast pressure distribution recommended by Chinese code
   - ✓ The cross-section bending resistance at rail seat of Australian concrete sleeper is high for stress which produce maximum bending moment at rail seat.
   - ✓ The cross-section bending resistance of German concrete sleeper at sleeper center is high when compared to others.

For FE result is clearly observed that the values of stress at both rail seat and sleeper center depends on the pattern of ballast pressure distribution under sleepers. The difference in stress result is due to the difference in cross-section rail seat and sleeper center, material properties and number of tendons. From both result the German concrete sleeper has performed well specially at sleeper center and the cross-section can be recommended for Ethiopian condition.

6.1. Recommendations

Generally, as it is explained in research objective the main aim is to compare the flexural performance (in bending resistance both at rail seat and sleeper center) of other countries prestressed concrete sleepers for the case of Ethiopian railway track design parameters. As we can observe from FE analysis it is difficult to recommend one countries concrete sleeper for Ethiopian case. All sleepers have their own advantage over the other. If we consider the general response the German concrete sleepers can be recommended. The response at rail seat of one sleeper is deferent from other which is true at sleeper center. For this thesis the ballast pressure distribution recommended by Chinese code is selected to recommend a cross-section at both rail seat and sleepers center. From the result, the cross-section bending resistance of Australian concrete sleeper at rail seat is selected whereas for sleeper center the German sleeper is selected. Therefore, from the two concrete sleepers we can obtain one sleeper cross-section which is to be recommended for Ethiopia as shown in Table 6.1 and Figure 6.1 below.

Table 6.1: Geometric properties

Item No	Sleepers	Sleeper length (mm)	Rail seat			Center		
			Bottom width (mm)	Top width (mm)	Height (mm)	Bottom Width (mm)	Top Width (mm)	Height (mm)
1	Recommended sleeper for Ethiopian case	2500	300	220	180	250	160	175

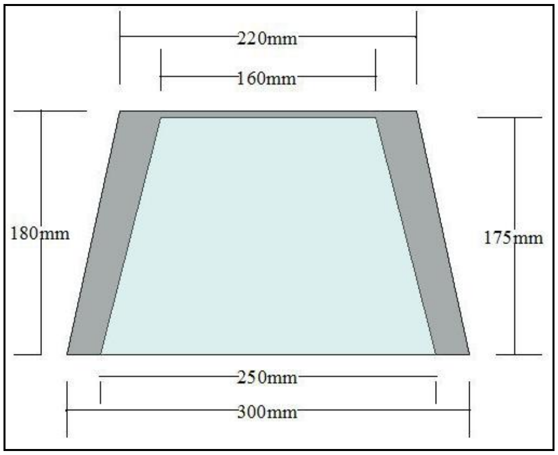


Figure 6.1: Cross-section properties of recommended sleeper

The following figures i.e. Figure 6.2 and 6.3 shows the stress results of the four countries concrete sleepers when compared with the newly commented concrete sleeper. From the analysis result it is observed that there is a reduction in stress values at both rail seat and sleeper center. For stress that produce maximum bending moment at rail seat a stress reduction of about 13.98% and 98.26 at rail seat and sleeper center has been observed. For the second case i.e. for the stress which produce maximum bending moment at sleeper center a 33.37 and 21.36% reduction in stress has been observed.

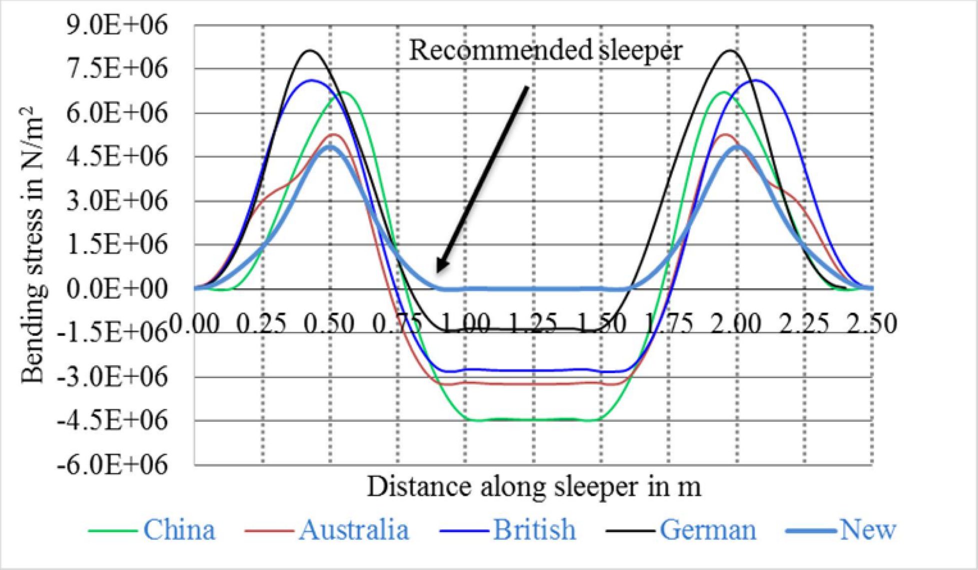


Figure 6.2: Stress which produce maximum bending moment at rail seat

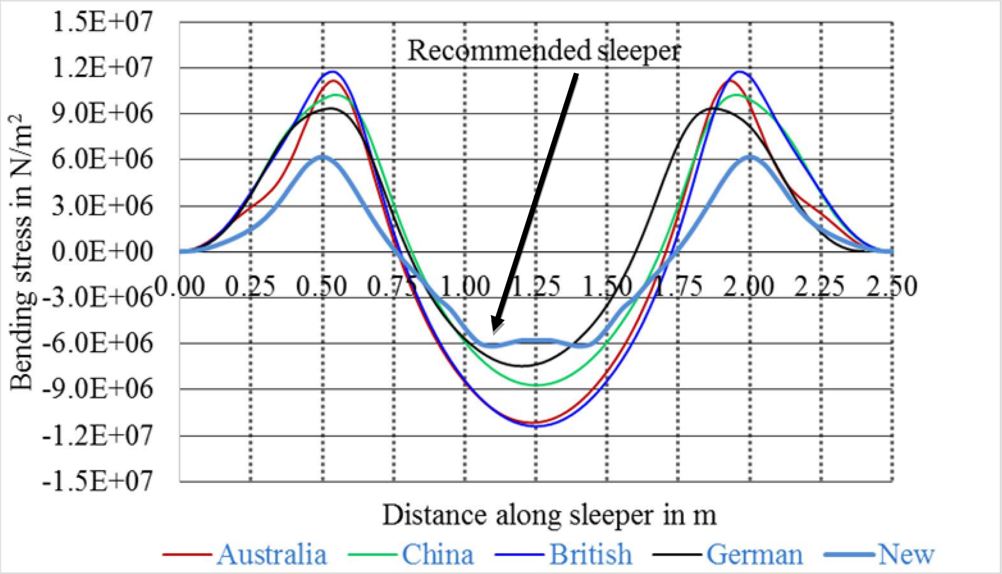


Figure 6.3: Stress which produce maximum bending moment at sleeper center

From the dynamic view point, the current design of railway prestressed concrete sleeper is to take a safety factor for dynamic load i.e. more than 250% percent of the static load. But these dynamic loads have a great impact on sleeper's flexural performance even though they occur for short periods. Different countries code like the Australian code discussed in chapter three recommends that, the effect of dynamic load can be included by taking 250% of static load. In the static analysis, this dynamic load has been included and it is sufficient to account for the effect of dynamic load effect. But, the dynamic analysis has been done to show how much these loads affect the flexural performance of concrete sleepers and they should be taken in to consideration during analysis and design of concrete sleepers.

6.2. Future works

- ✓ In this thesis only static and dynamic loads have been considered, therefore other loading condition like accidental, exceptional and lateral loads can be considered for further study.
- ✓ Optimization (in terms of geometry) can be done.
- ✓ Optimization in terms of ballast pressure distribution can be considered.
- ✓ The interaction (Contact) between ballast and sleeper can be considered for future works.

Reference

American Railway engineering and Maintenance-of-Way Association (AREMA), (2010) Manual for Railway Engineering Volume 1, Track, USA.

Australian railway track corporation (ARTC), 2013 Section 2: Sleepers and Fastenings, Australia.

Australian Railway Track Corporation LTD. (2013), Sleepers and Fastenings Code of Practice version 2.5, 2013.

Bernhard, L. (2005) Track compendium, EurailpressTetzlaff-Hestra GmbH & Co. KG, 2005.

BS EN 13230-1. (2014), Railway application, Track, Concrete sleeper and barriers-general requirements.

Clifford F Bonnett. (1996) Practical Railway Engineering, London: Imperial College press.

Committee CE-002. 2003 Railway Track Materials, Australian Standard: Part 14 Prestressed concrete sleepers, 3rd edition, Australia: Standards Australia International Ltd.

Coenraas Esveld. (2001) Modern Railway track, Second Edition, Netherland: MRT Productions.

Economic and Planning Research Institute of Ministry of Railways, (2005) TB10082: Code for Design of Railway Track, Beijing.

EN 13230-1, (2009) Railway applications, Track - Concrete sleepers and bearers -Part 1: General requirements.

ERC, (2011) The National Railway Network of Ethiopia, [online], http://www.erc.gov.et/index.php/projects/national-railway-network-of-ethiopianrne.html.

iCivil Engineer, [online], http://civilengineerme.blogspot.com/2012/04/requirements-of-ideal-sleeper.html.

John C. Zeman, J. Riley Edwards, Christopher P.L. Barkan, and David A. Lange. (2007) Failure Mode and Effect Analysis of Concrete Ties in North America.

J.S.Mundrey. (2000) Railway track Engineering, (India): Tata McGraw-Hill.

J. Taherinezhad, M. Sofi, P. A. Mendis and T. Ngo. (2013) A Review of Behaviour of Prestressed Concrete Sleepers, vol. 13(1).

KonstantinosTzanakakis. (2012) The Railway Track and Its Long Term Behaviour: A Handbook for a Railway Track of High Quality, Athens: Springer.

K. Riessberger. 2012 ‘Increasing Railway Stability with Support element’, Civil Engineering and Architecture vol. 55 No. 2.

American Railway engineering and Maintenance-of-Way Association (AREMA), (2010) Manual for Railway Engineering Volume 1, Track, USA.

Pankhurst, R. (2006), The Franco-Ethiopian Railway and Its History, [online], Available http://tezeta.net/37/the-franco-ethiopian-railway-and-its-history.htm.

RAIL SYSTEM NET, [online], Available: http://www.Railsytem.Net/sleeper.htm.

RAIL.ONE GmbH. Concrete sleepers concrete elements. (2013), www.railone.com, Germany

RAIL.ONE GmbH. Different types concrete sleepers, www.railone.com, Germany.

RAIL.ONE GmbH (2004), wide sleepers track, Available: http://www.railone.com/wide sleepe.htm, [2004].

Rasiah Sri Ravindrarajah and Stephen R. White. (2014) Non-Delayed Heat Application Effects on The Strength of Concrete for Railway Sleepers, Vol. 5(1).

Sakdirat KAEWUNRUEN and Alex M REMENNIKOV. (2006), ‘Peer-reviewed: Nonlinear finite element modeling of railway prestressed concrete sleeper’, East Asia-Pacific

Conference, Bangkok, Thailand. SSL-Schwellenwerk and Steuerungstechnik. [Online], Available: http://www.ssl-linz.at/sleeper/rs115.pdf.

Shan Li. (2012) Railway Sleeper Modeling with Deterministic and Non-deterministic Support Conditions: Master Degree Project,Stockholm.

Vassilios A. Profillidis. (2006), Railway Management and Engineering, Avebury Technical: England.

V.A PROFILLIDIS. (1995) Railway Engineering, England: Ashgate Publishing Limited.

Zhe Chen, Moochul Shin, BassemAndrawes. (2012) Numerical Simulation of Prestressed Concrete Crosstie and Fastening System.